SCAG Arterial Speed Study – Phase 2

Final Report

Prepared for:
Southern California Association of Governments

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July 17, 2009

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Mike Ainsworth

Southern California Association of
Governments
3600 Lime St.
Riverside, CA 92501

Subject: **Final Report for SCAG Arterial Speed Study – Phase 2** SCAG: 07 – 041

Dear Mr. Ainsworth:

Dowling Associates is pleased to submit this final report for the SCAG Arterial Speed Study, Phase 2 (SCAG contract no. 07 – 041). This is the final deliverable for this project.

I wish to thank the technical staff of SCAG – Mike Ainsworth and Guoxiong Huang – for their timely reviews and suggestions throughout this project.

I also wish to acknowledge the contributions of our subconsultants. Thomas Carlson of Sierra Research helped develop the sampling plan, and carried out the research on truck speeds. Steve Taylor and Sudheer Dhulipala of Jacobs Engineering (Carter-Burgess) programmed the GPS units for the arterial speed survey and reduced the data for analysis. Mr. Moses Wilson of WILTEC was supervised the arterial surveys.

Please call either me (extension 120) or David Reinke (extension 104) if you have any questions.

Sincerely,

Dowling Associates, Inc.

Richard G. Dowling, Ph.D., P.E.
Principal

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1 Introduction

This report presents the results of Phase 2 of the SCAG Arterial Speed Study. This study had the following objectives:

- Develop a sample of 24 sites for arterial speed surveys.
- Conduct arterial speed surveys at the 24 sites and combine these data with data from the 8 sites surveyed in Phase 1.
- Collect data on freeway speeds and volumes for estimation of a volume-delay function (VDF).
- Carry out tabulations on the speed and flow data.
- Create a database of arterial and freeway speeds and flows to be incorporated into the Regional Highway Inventory database.
- Develop new VDFs for freeways and arterials.
- Assist SCAG with validating the new VDFs.
- Develop a framework for improving SCAG's truck speed model.

This report is a compilation of technical memoranda that have been produced as products of these tasks:

- Section 2 discusses development of the arterial speed survey sample and the field procedures for the survey
- Section 3 discusses the combined arterial/freeway speed-flow database and presents summary analyses of the data.
- Section 4 discusses the initial estimation of the arterial VDF
- Section 5 discusses the initial estimation of the freeway VDF
- Section 6 discusses the analysis of truck speeds and presents a framework for analyzing truck speed data
- Section 7 discusses the VDF model validation and revision, and presents a set of recommended parameter ranges for the arterial and freeway VDFs.

2 Arterial Speed Surveys

2.1 Sampling Plan

The following procedures were used to guide sample selection:

- Counties were sampled in proportion to VMT in the county.
- At least one sample is to be collected from each county.
- The sample focuses on congested facilities; i.e., where the SCAG model shows a V/C > 1 during the peak.

An initial set of arterial segments was selected for sampling based on the above criteria. The limits of each segment were set to allow drivers to make a round trip within a 15-minute period, corresponding to the traffic count periods.

Table 2-1 shows VMT and delay for AM and PM peak periods combined. The table also shows what the sample sizes would be if the sample were strictly allocated according to VMT or delay.

County	VMT	VHT	Delay	% VMT	% Delay	Sample size based on:*	
						VMT	Delay
Imperial	3,177,332	69,707	7,547	1%	0%	0	0
Los Angeles**	118,372,744	5,069,747	2,133,791	51%	62%	16	20
Orange	39,885,614	1,549,317	609,970	17%	18%	6	6
Riverside	26,652,285	876,865	315,974	12%	9%	4	3
San Bernardino	32,227,091	953,542	280,540	14%	8%	4	3
Ventura	10,550,382	341,745	107,691	5%	3%	2	1
Region Total	230,865,448	8,860,923	3,455,513			32	32

*Totals may not add to 32 due to rounding
** Los Angeles sample includes 8 segments sampled in Phase 1 study

Table 2-1. Summary statistics from SCAG model runs: AM and PM peak periods

It was decided to allocate the sample somewhat less than proportionally to VMT or delay in order to provide greater coverage of Orange, Riverside, San Bernardino, and Riverside counties. Only two congested facilities could be found in Imperial County; one of these was chosen for the sample.[1]

An initial sampling plan was presented to SCAG. After comments by SCAG technical staff, we jointly made several modifications to the sample to improve coverage and

[1] Sampling the other facility in Imperial County would have entailed a border crossing, which rendered it infeasible for the sample.

reduce the lengths of some sections. A summary of the number of samples by county is presented in Table 2-2.

County	Abbr.*	Samples
Imperial	IM	1
Los Angeles	LA	6
Orange	OR	5
Riverside	RV	4
San Bernardino	SB	4
Ventura	VN	4
Total		24

* The abbreviation used for the sample identifier in Table 3.

Table 2-2. Number of samples by county

A detailed listing of the final sample is presented in Table 2-3. Note that a sample ID number was assigned to all candidate sample locations; the sample numbers are the sample IDs for those samples that were selected. A letter suffix (e.g., SB 01b) indicates a length modification of an original sample location.

Sample ID	City	Location			Art type	O/W dist (mi)
		Street	From	To		
IM 01b	Calexico	W Birch St (SR98)	Imperial Ave.	Andrade Ave	4	0.9
LA 01	Compton	E Rosecrans Ave	N Willow brook Ave	Atlantic Ave	4	1.8
LA 02	La Puente / West Covina	N Hacienda Blvd (SR39)	N Unruh Ave	E Cameron Ave	4	1.7
LA 03	Long Beach	E Anaheim St	Junipero Ave	Clark Ave	5	1.7
LA 04	La Habra Heights	N Harbor Blvd	Fullerton Rd	Orange County Line	4	0.7
LA 05	La Puente / Hacienda Heights	7th Ave	Valley Blvd	Palm Ave	4	1.5
LA 06	Castaic	Henry Mayo Dr (SR126)	Chiquito Canyon Rd	Pico Canyon Rd	4	1.6
OR 01	E of Tustin	E Santiago Canyon Rd	Jamboree Rd	SR241 on ramp	4	1.5
OR 02	Anaheim	W Broadway Ave	N Euclid St	S Harbor Blvd	5	1.3
OR 03	Fullerton	N State College Blvd	Yorba Linda Blvd	Imperial Hwy (SR90)	4	1.5
OR 04	Fountain Valley / Costa Mesa	Talbert Ave	Brookhurst	Harbor Blvd	4	2.0
OR 05	La Habra	Hacienda Rd (SR39)	W Whittier Blvd	Citrus St	4	0.8
RV 03	Riverside	Van Buren Blvd	Victoria Ave	Mockingbird Canyon Rd	4	2.2
RV 04	Perris	N Perris Blvd	E 11th St	Nuevo Rd	4	1.8
RV 06	Riverside	Washington St	Overlook Pkwy	Golden Star Ave	5	2.5
RV 08	Riverside	Market St	SR 60 (EB off)	University Ave	4	1.4
SB 01b	San Bernardino	University Pkwy	Hallmark Pkwy	Northpark Blvd	5	1.4
SB 02b	Bloomington	Cedar Ave	Bloomington Ave	Rialto Ave	5	1.9
SB 04	Chino Hills	Central Ave	Schaefer Ave	SB on-ramp to NB SR71	4	2.3
SB 07	Rialto	E Rialto Ave	Acacia Ave	Rancho Ave	5	1.6
VN 01	Moorpark	Moorpark Rd	Read Rd	Tierra Rejada Rd	5	1.0
VN 02	Camarillo	Pleasant Valley Rd	Springville Rd	S Lewis Rd	4	1.0
VN 05	Oxnard	N Rice Ave	Camino Del Sol	Channel Islands Blvd	4	2.3
VN 06	Simi Valley	Madera Rd	Wood Ranch Pkwy	E Los Angeles Ave / Tierra Rejada Rd	4	2.0

Table 2-3. Arterial speed survey sample

The maps in Figure 2-1 and Figure 2-2 show the locations of the speed survey samples.

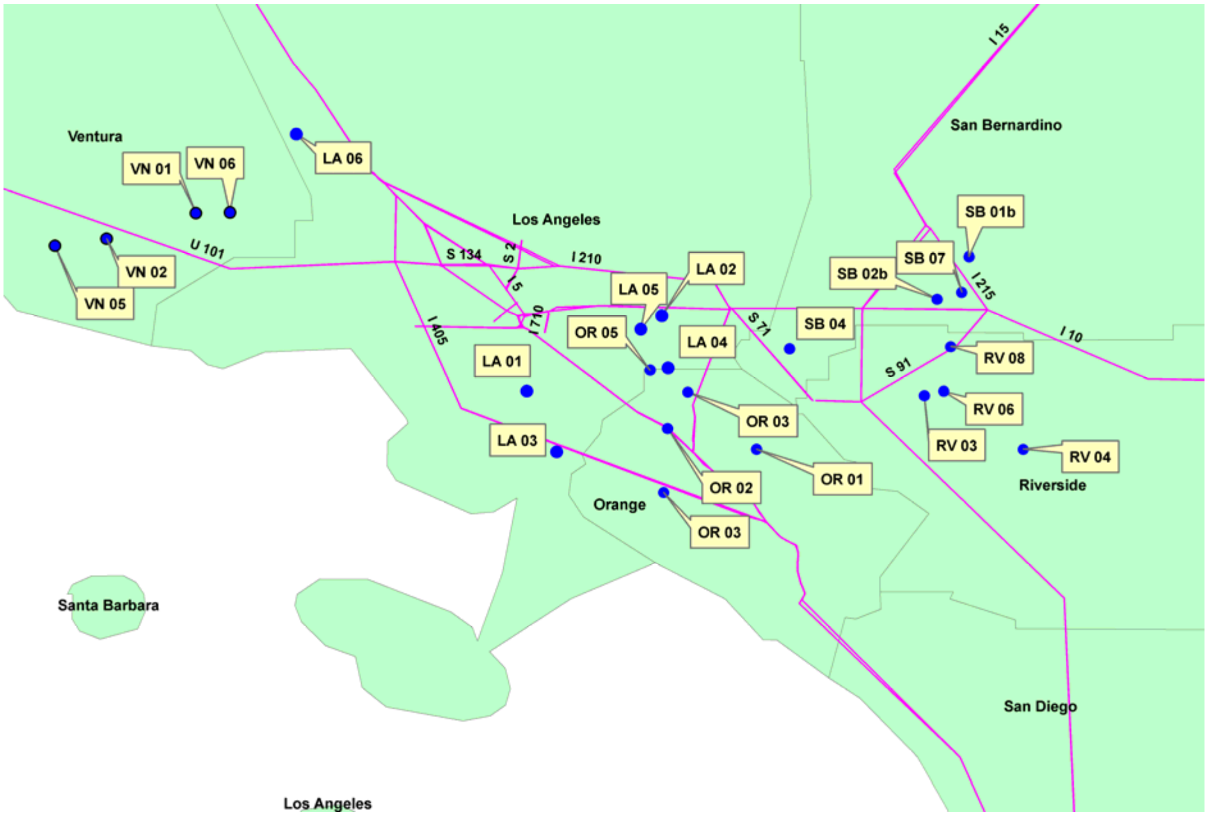

Figure 2-1. Phase 2 arterial speed survey locations (excluding Imperial County)

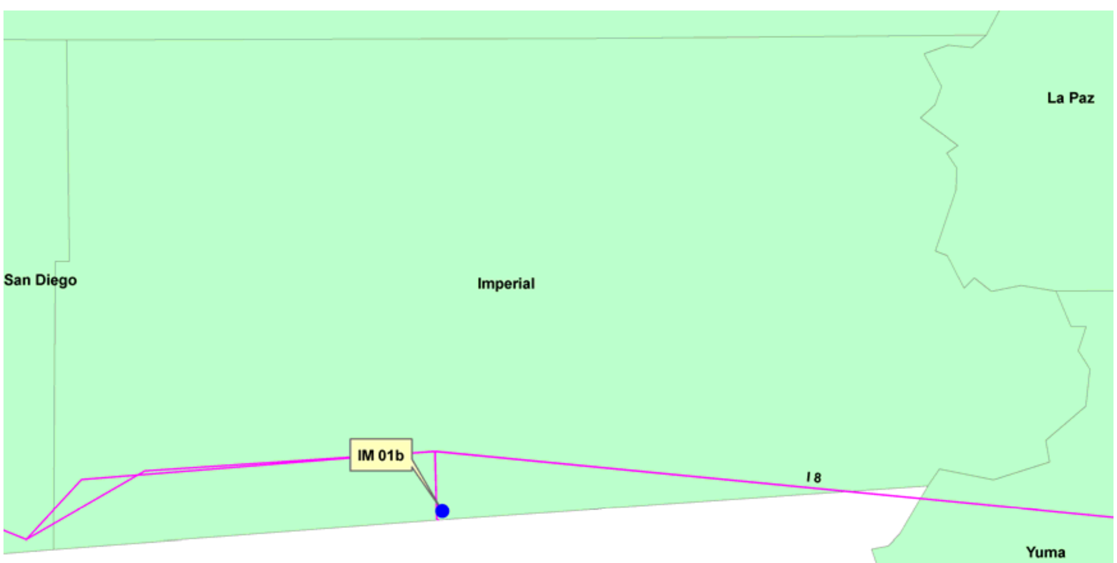

Figure 2-2. Arterial speed survey location in Imperial County

Details for each sample are shown in Figure 2-3 through Figure 2-26 on the following pages.

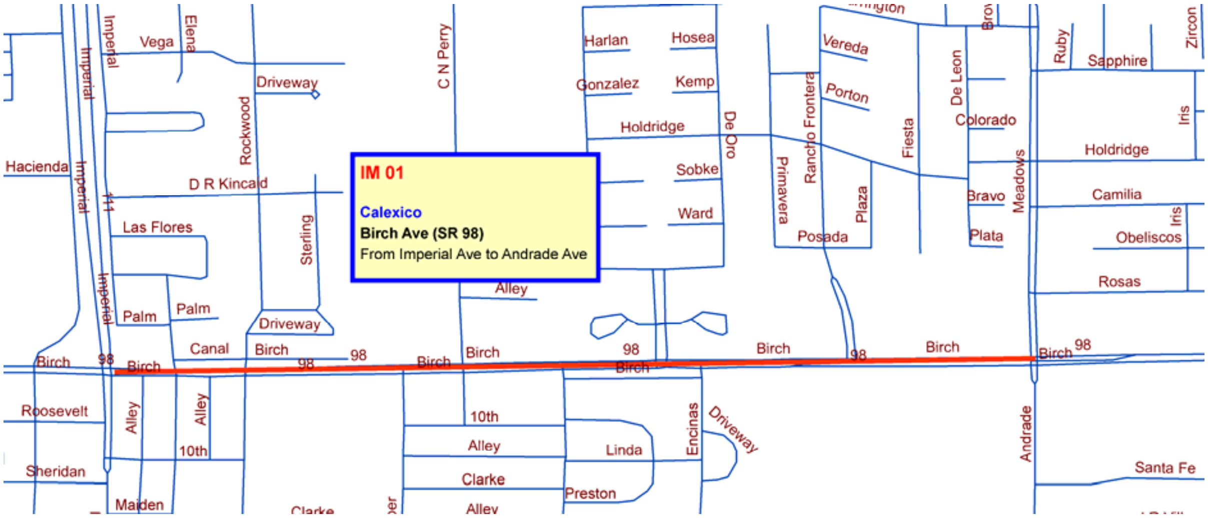

Figure 2-3. Arterial speed survey sample IM 01b detail

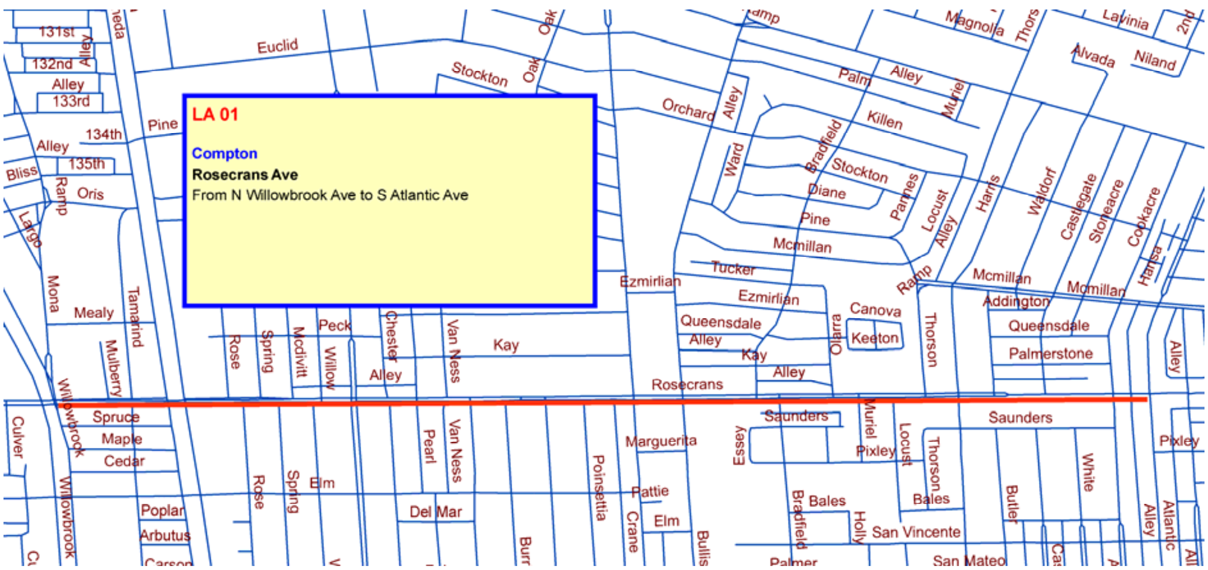

Figure 2-4. Arterial speed survey sample LA 01 detail

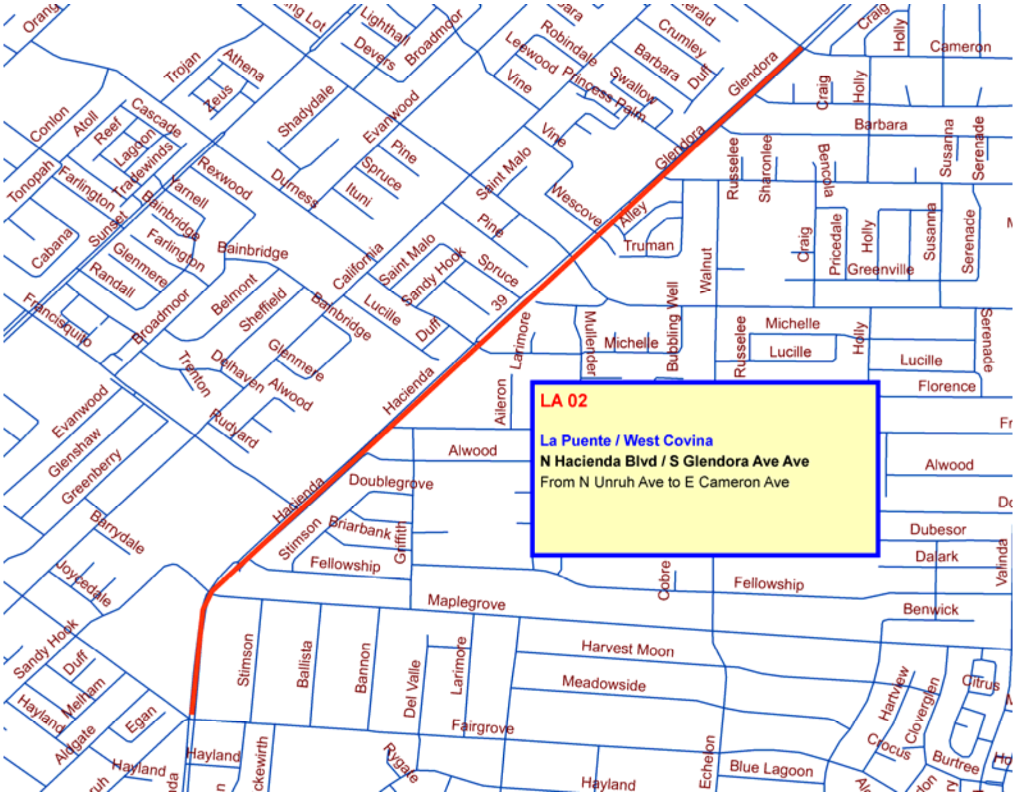

Figure 2-5. Arterial speed survey sample LA 02 detail

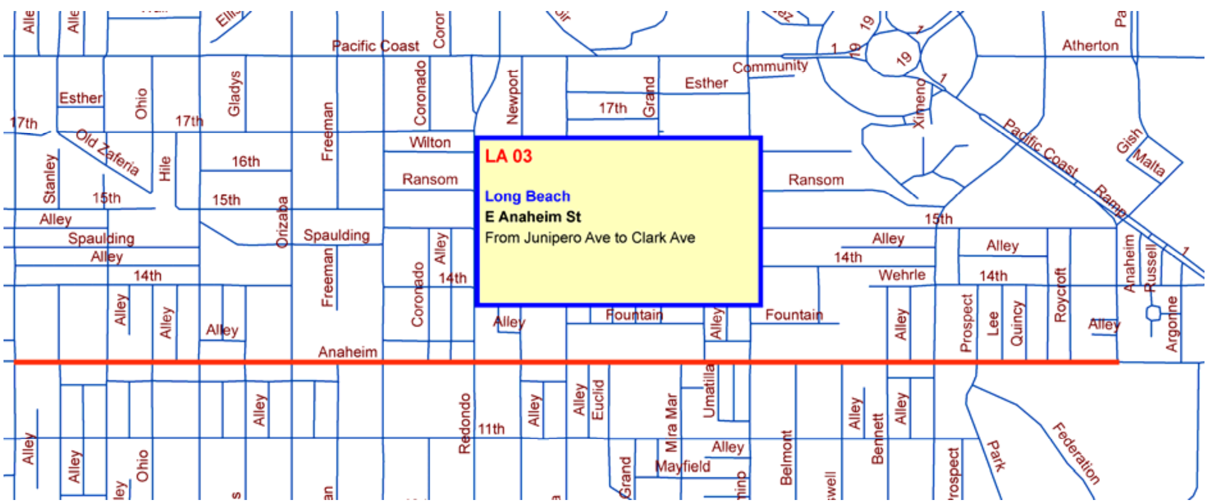

Figure 2-6. Arterial speed survey sample LA 03 detail

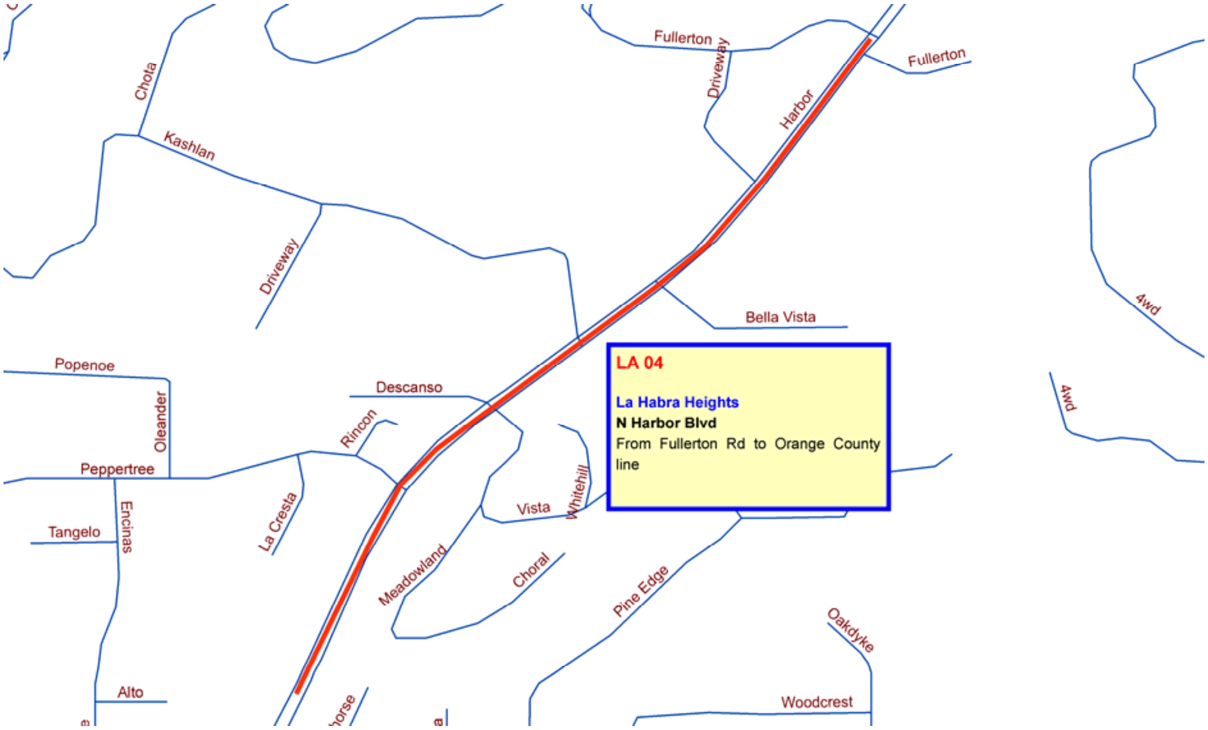

Figure 2-7. Arterial speed survey sample LA 04 detail

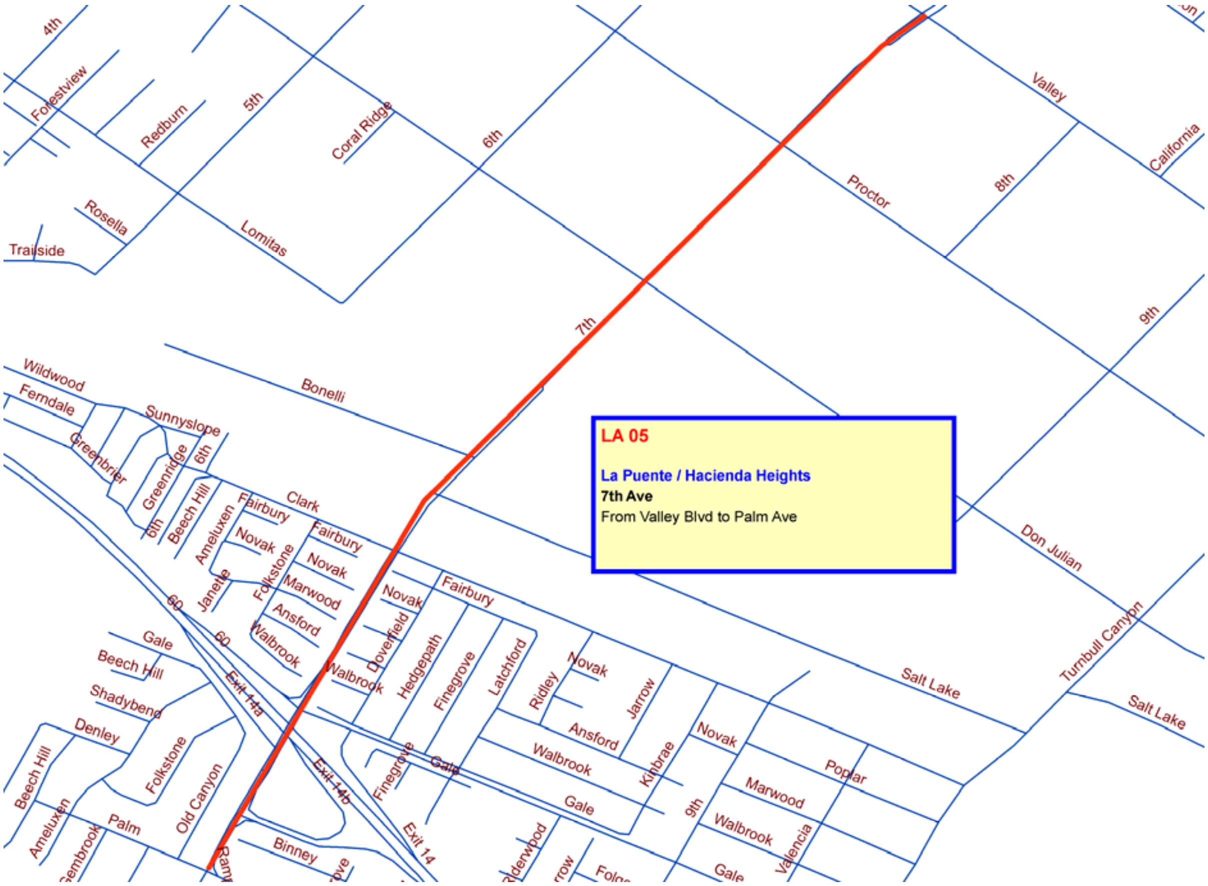

Figure 2-8. Arterial speed survey sample LA 05 detail

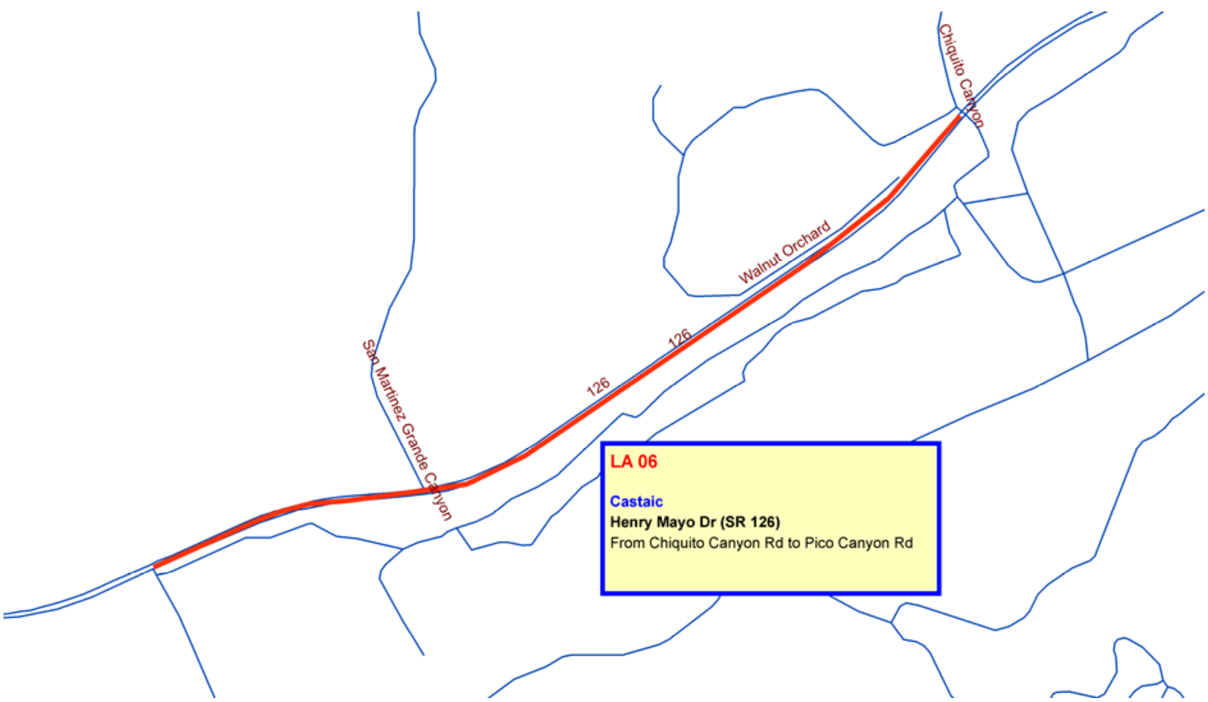

Figure 2-9. Arterial speed survey sample LA 06 detail

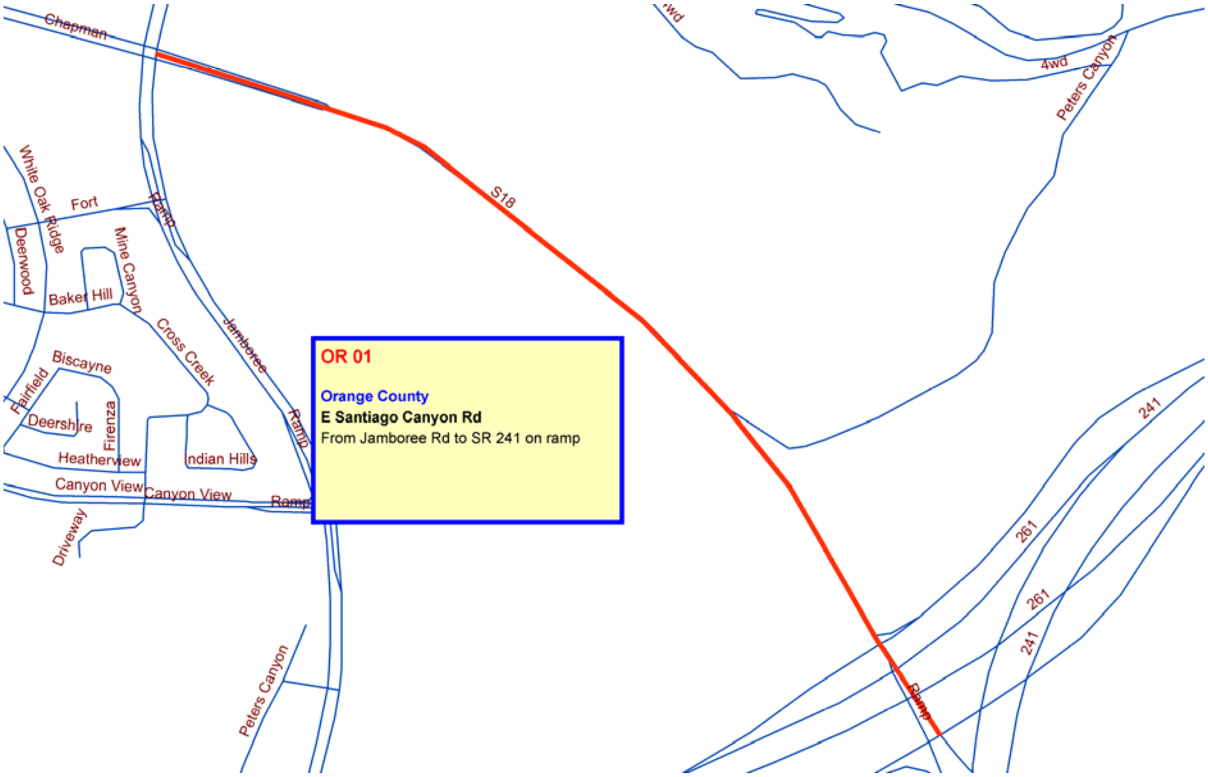

Figure 2-10. Arterial speed survey sample OR 01 detail

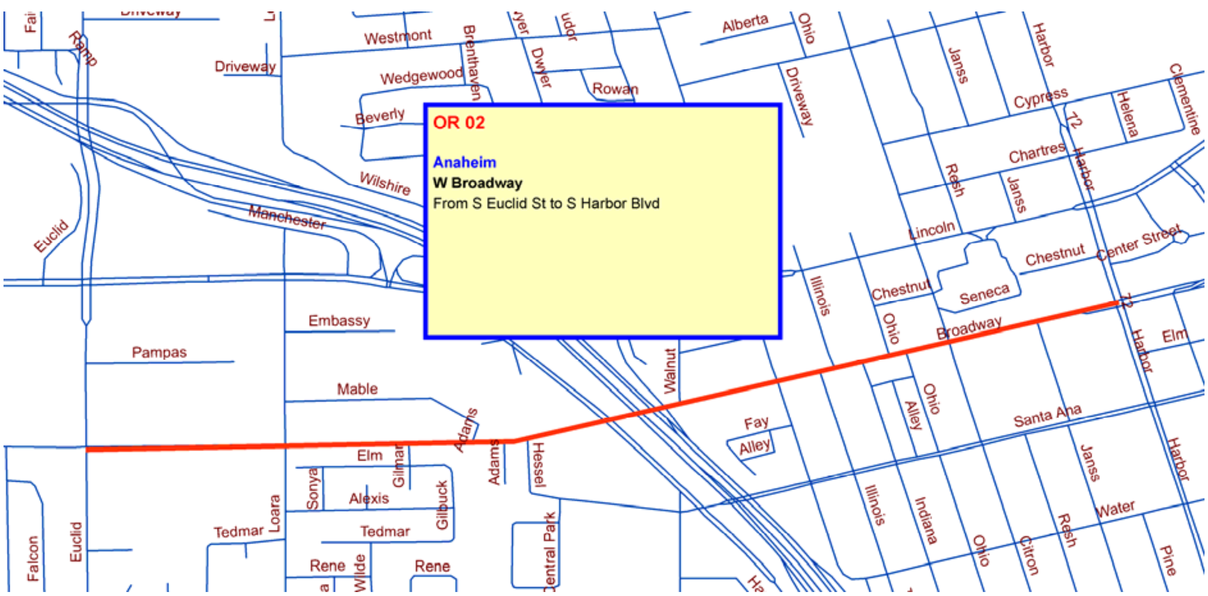

Figure 2-11. Arterial speed survey sample OR 02 detail

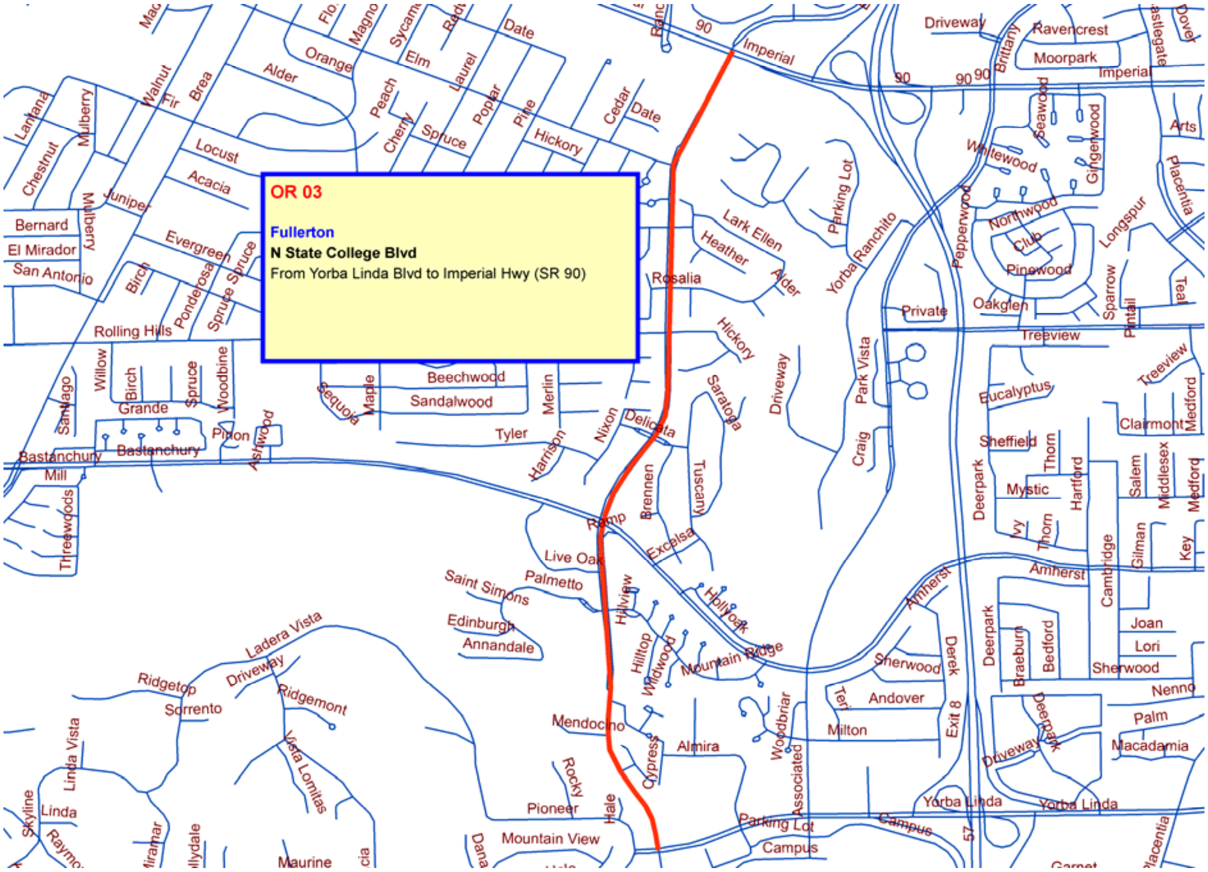

Figure 2-12. Arterial speed survey sample OR 03 detail

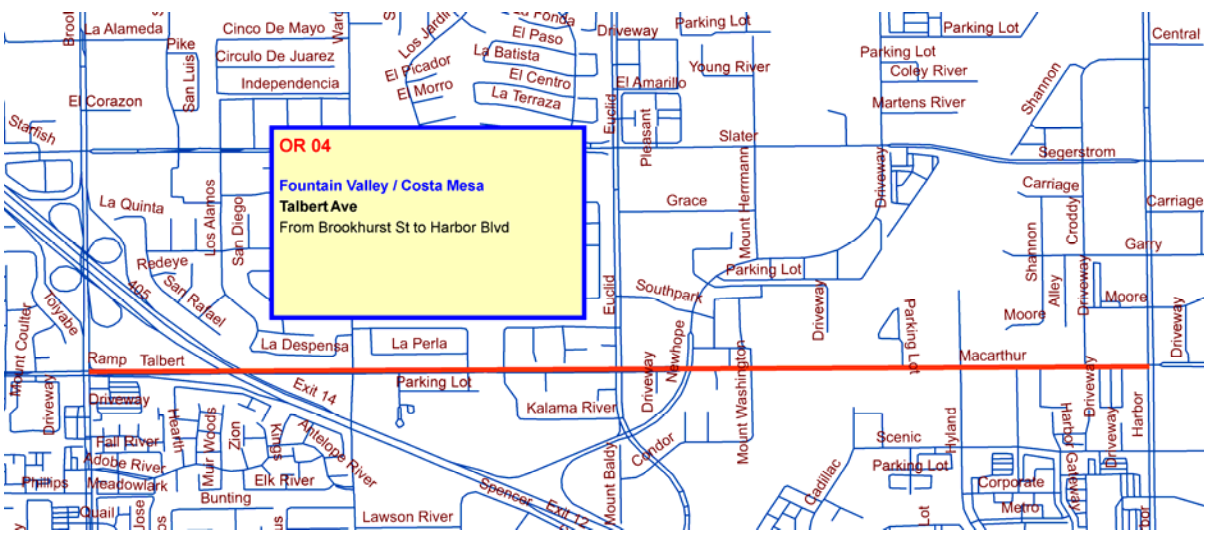

Figure 2-13. Arterial speed survey sample OR 04 detail

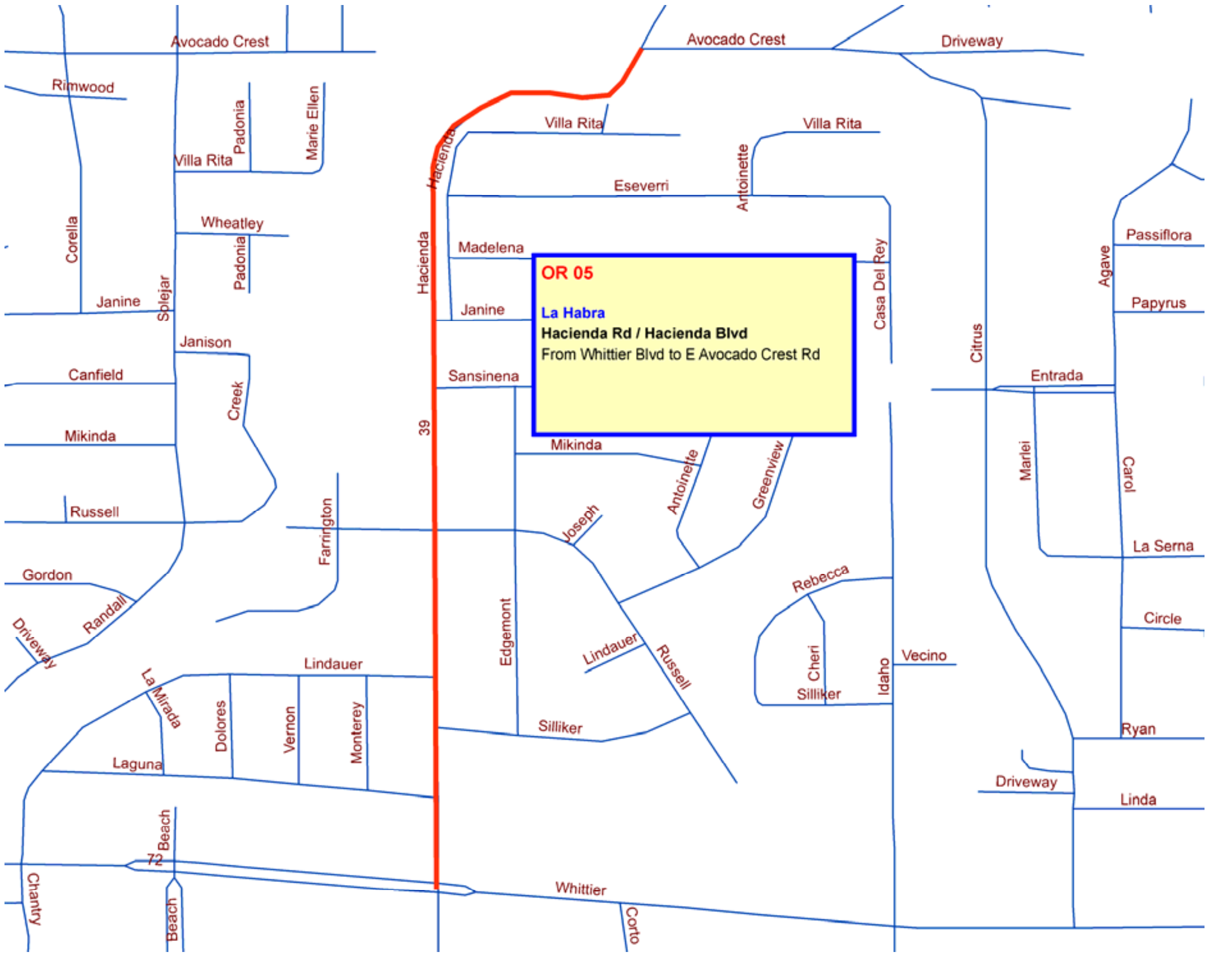

Figure 2-14. Arterial speed survey sample OR 05 detail

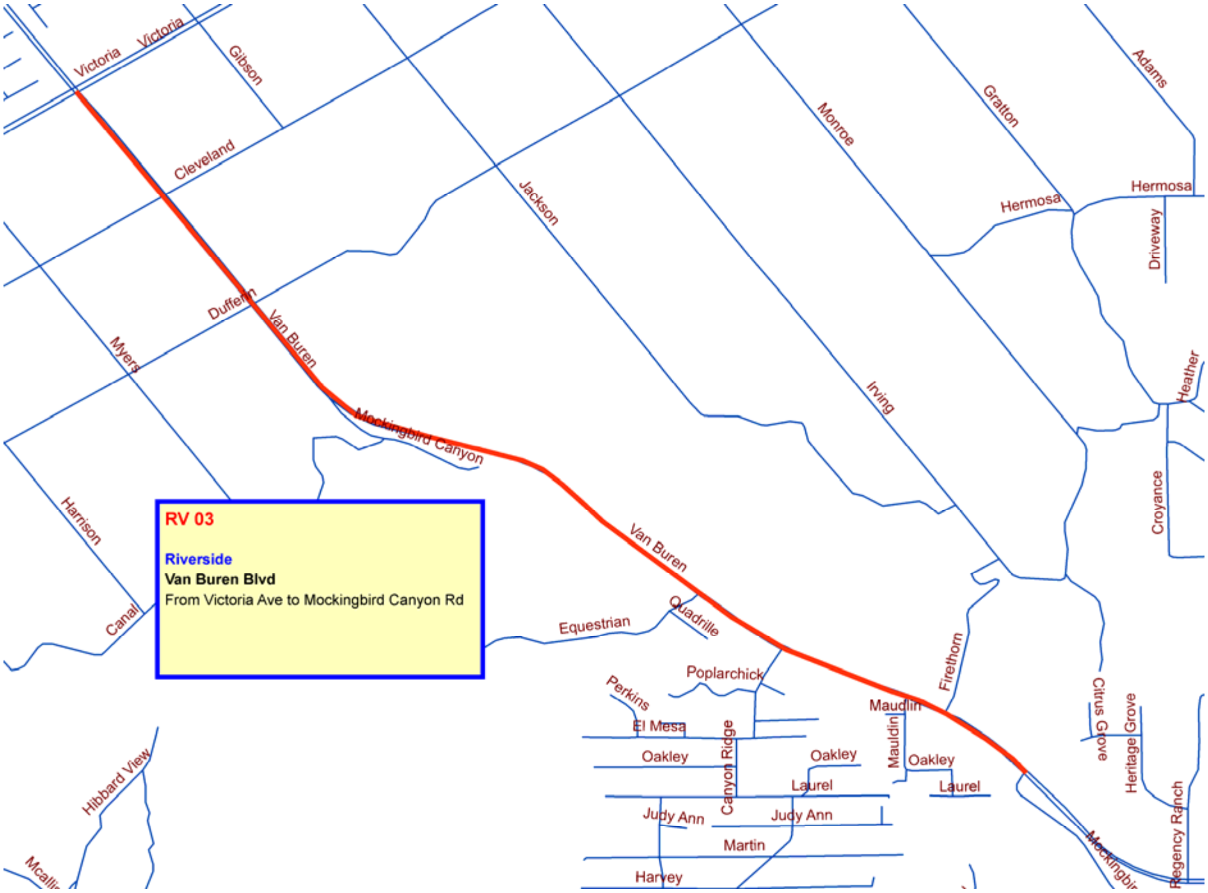

Figure 2-15. Arterial speed survey sample RV 03 detail

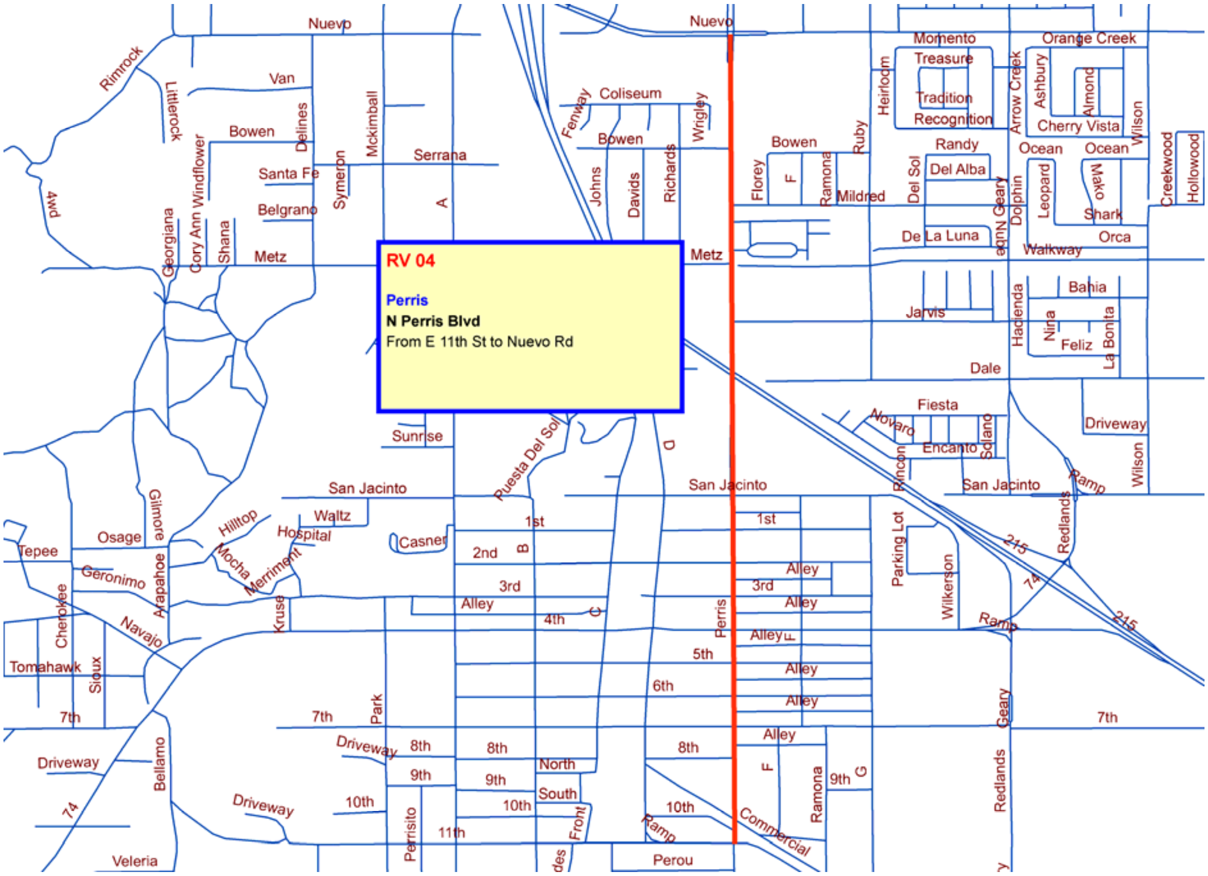

Figure 2-16. Arterial speed survey sample RV 04 detail

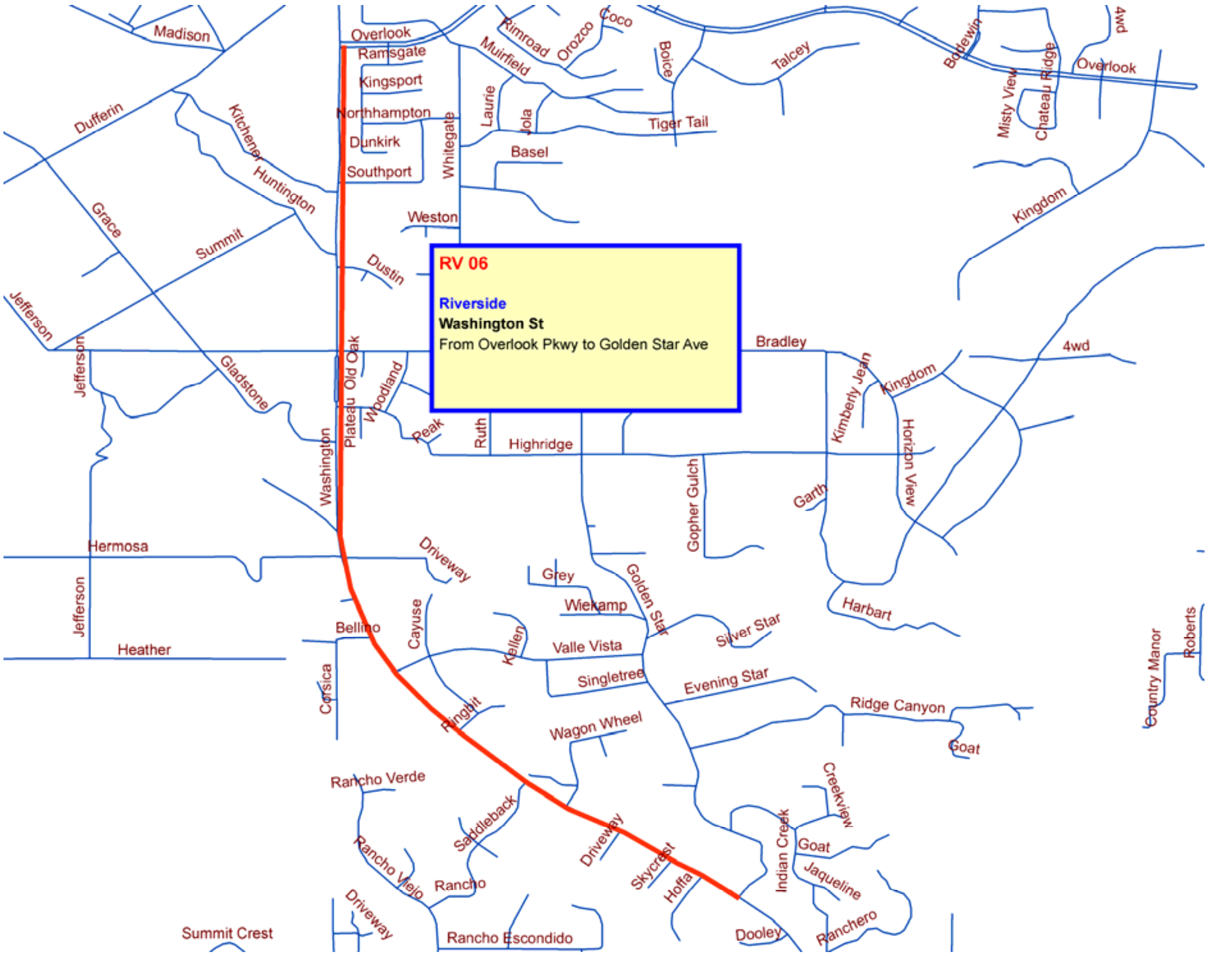

Figure 2-17. Arterial speed survey sample RV 06 detail

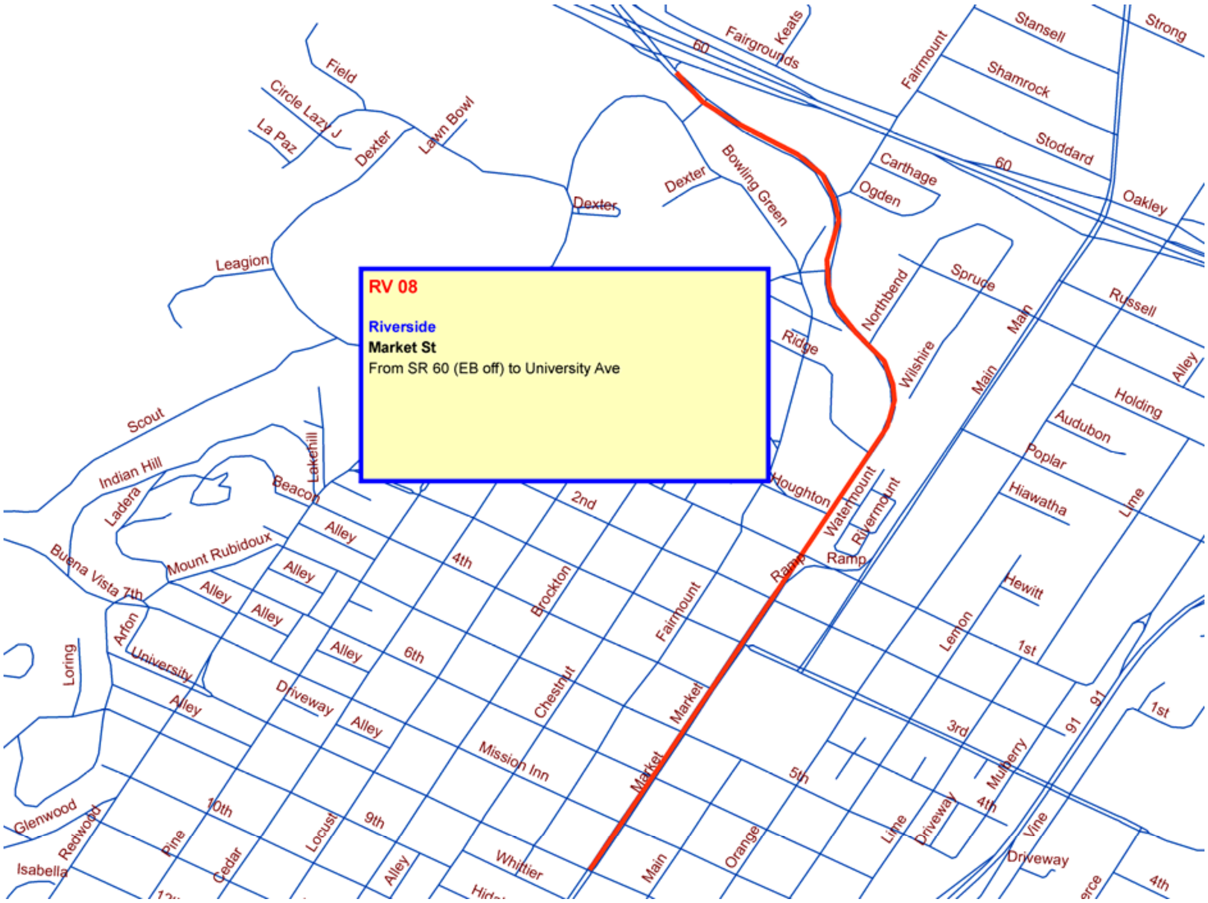

Figure 2-18. Arterial speed survey sample RV 08 detail

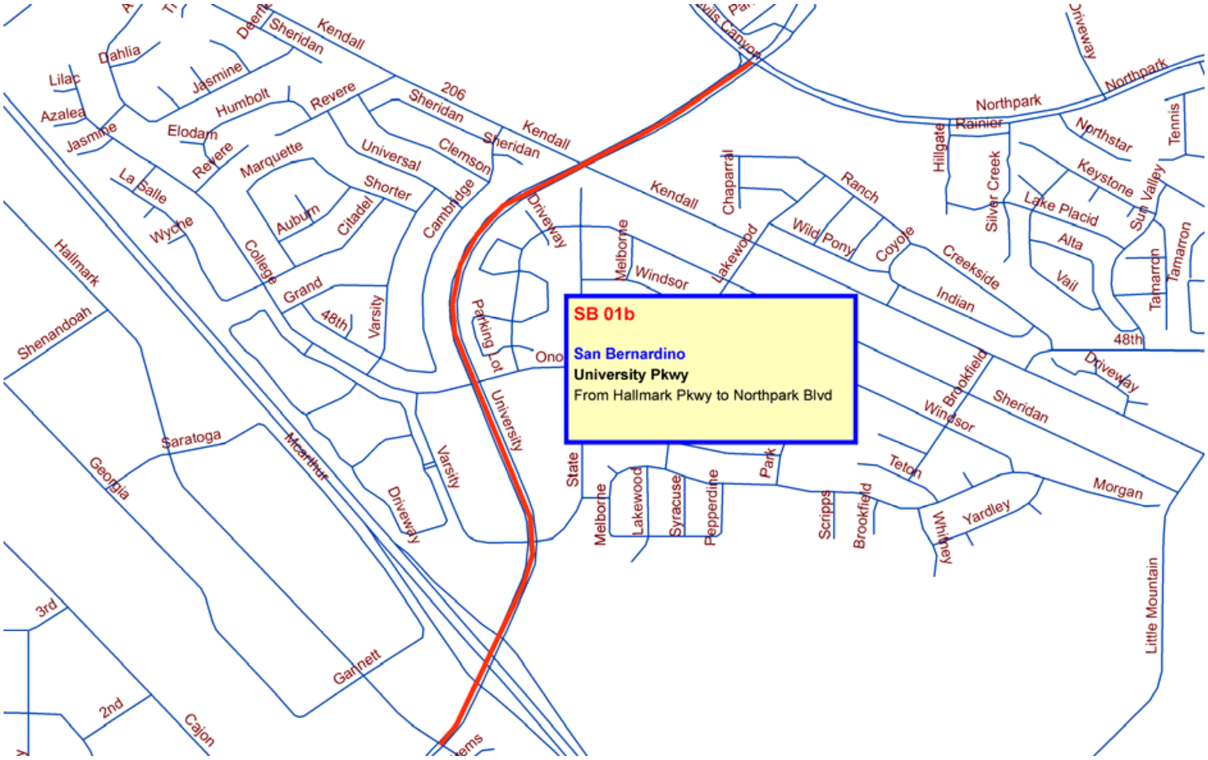

Figure 2-19. Arterial speed survey sample SB 01b detail

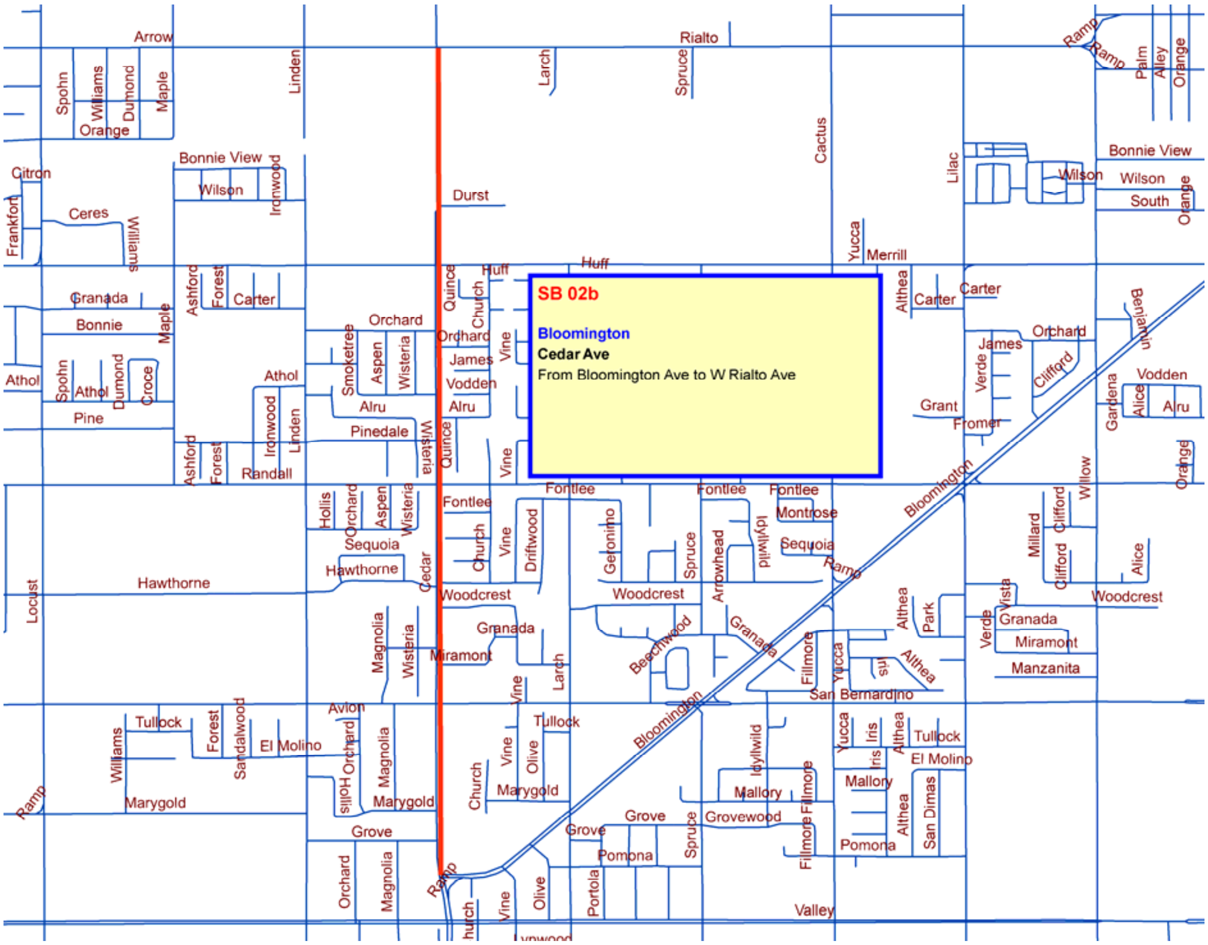

Figure 2-20. Arterial speed survey sample SB 02b detail

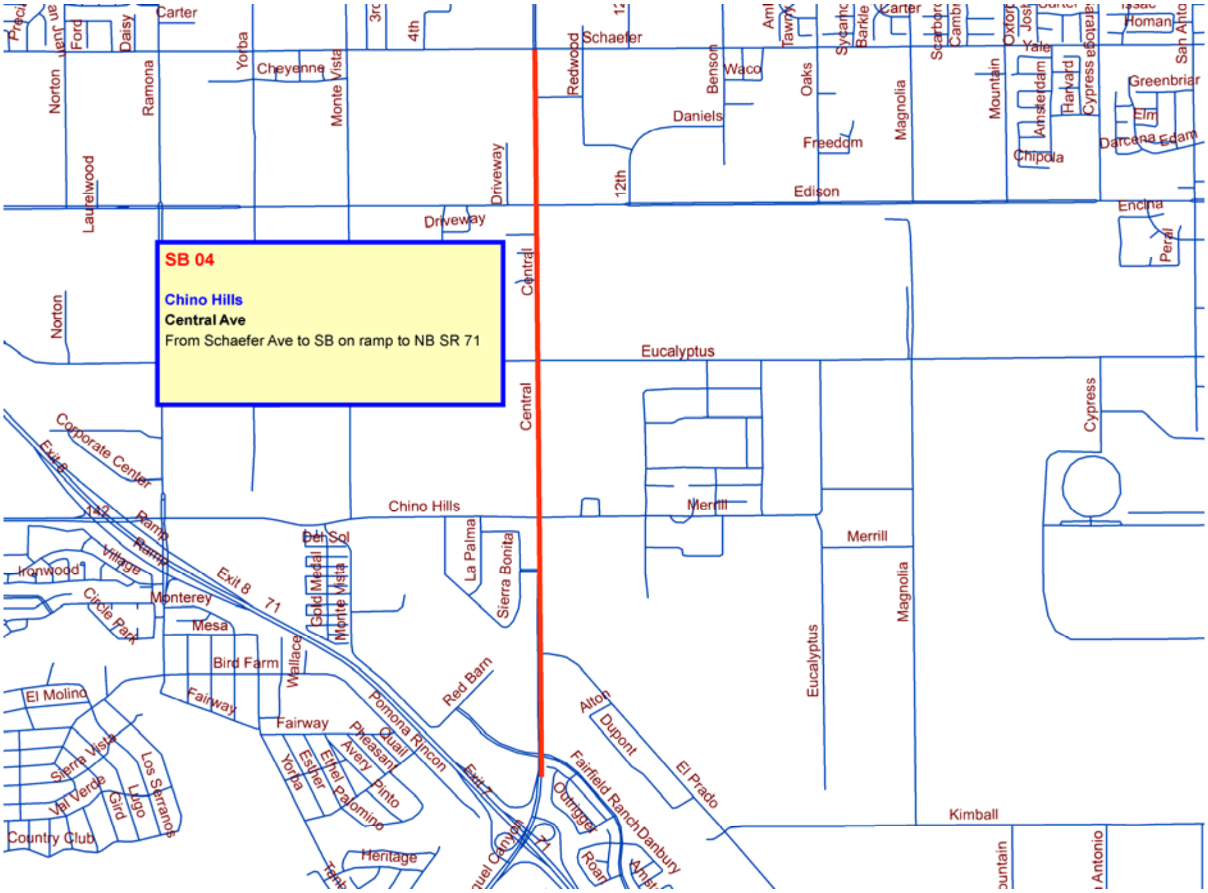

Figure 2-21. Arterial speed survey sample SB 04 detail

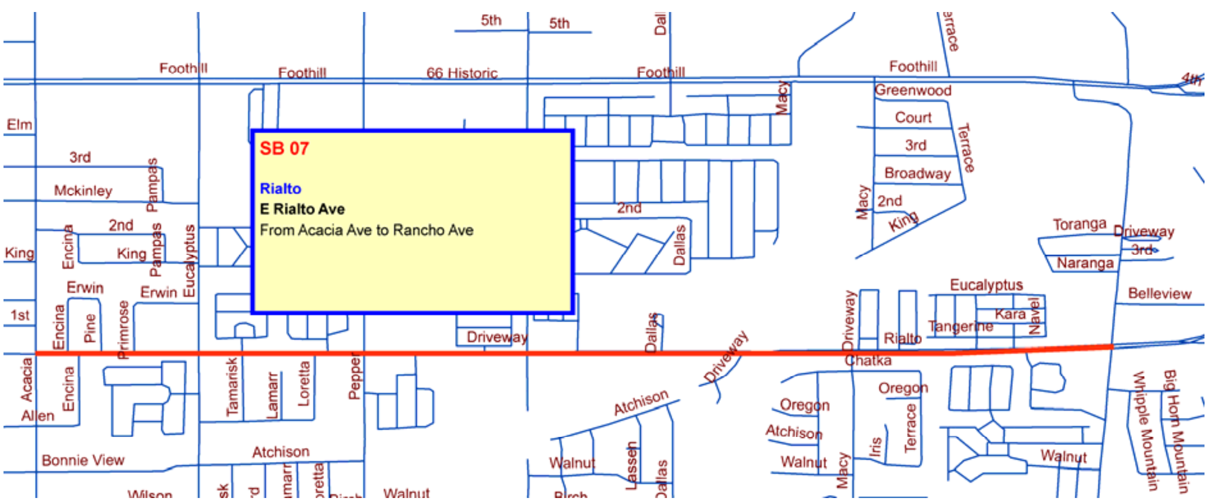

Figure 2-22. Arterial speed survey sample SB 07 detail

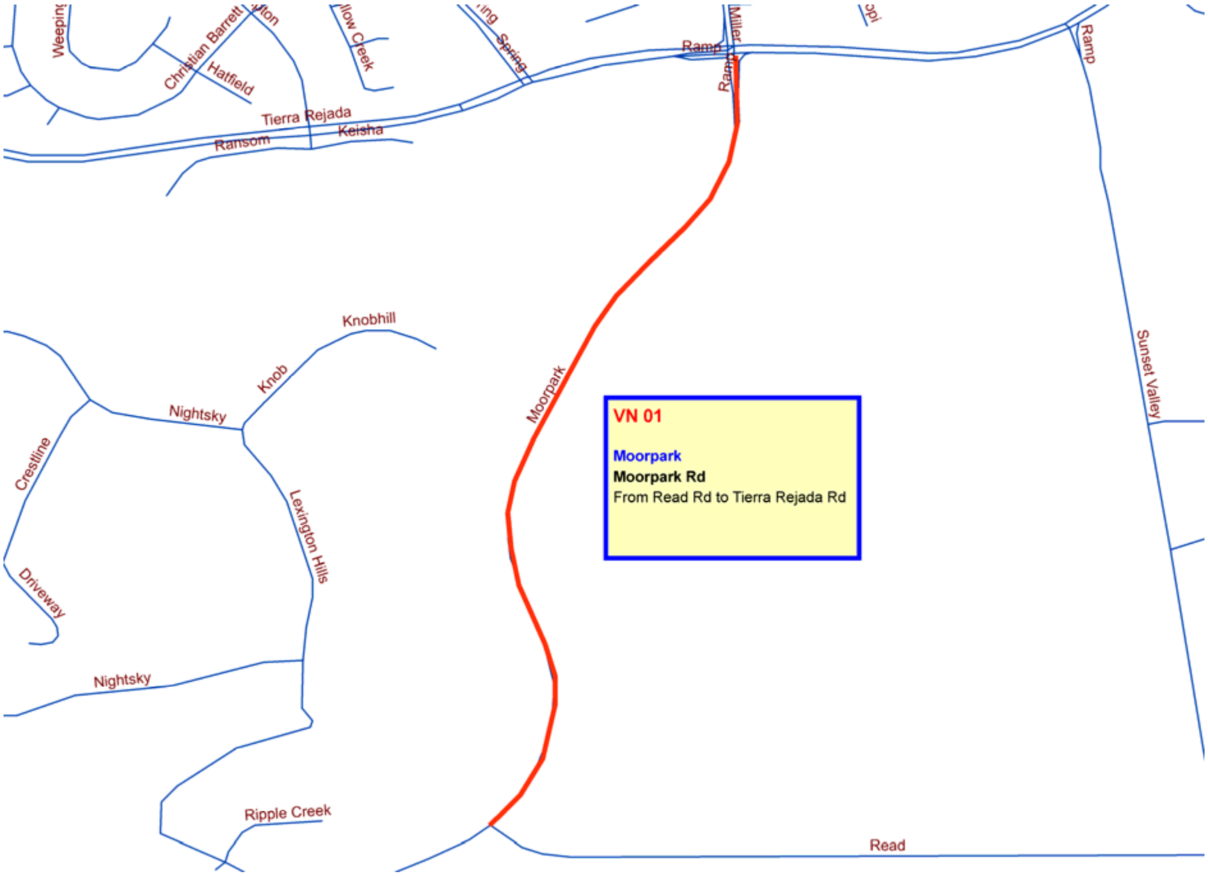

Figure 2-23. Arterial speed survey sample VN 01 detail

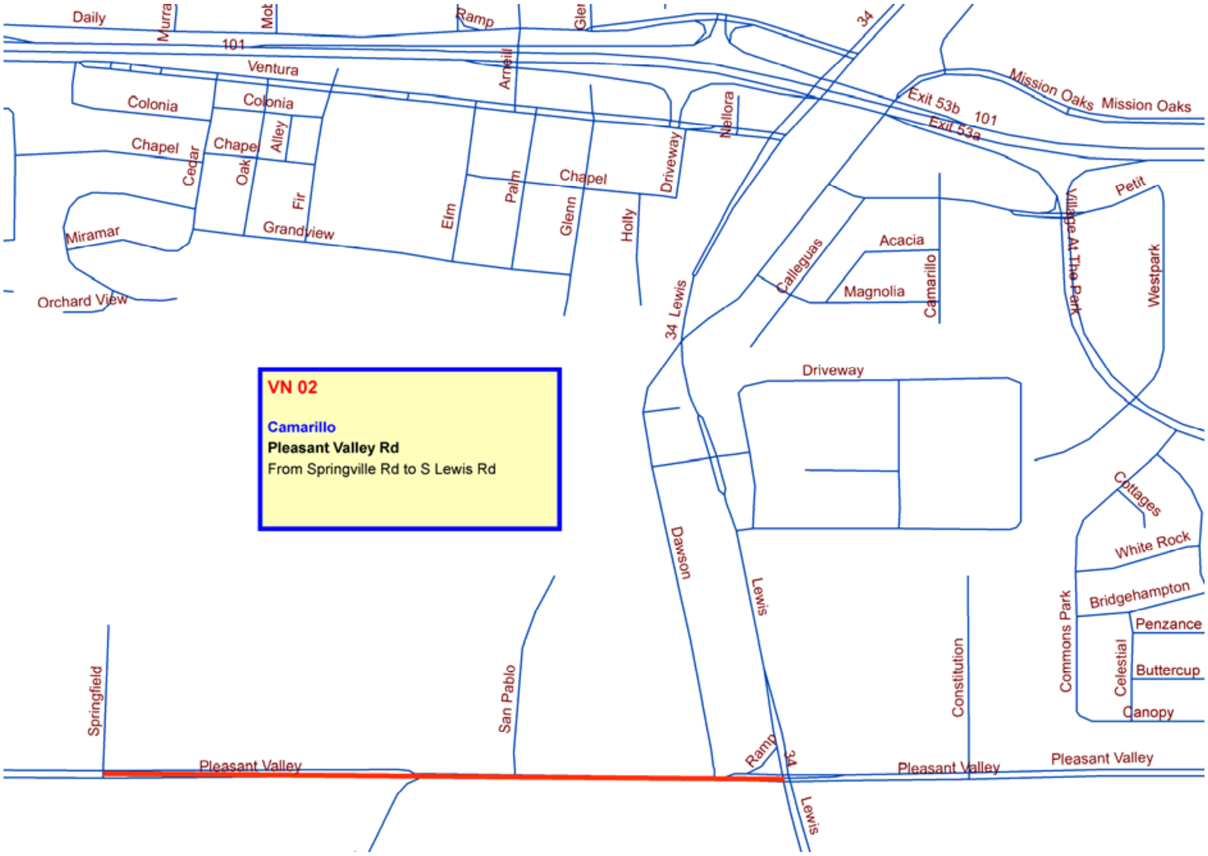

Figure 2-24. Arterial speed survey sample VN 02 detail

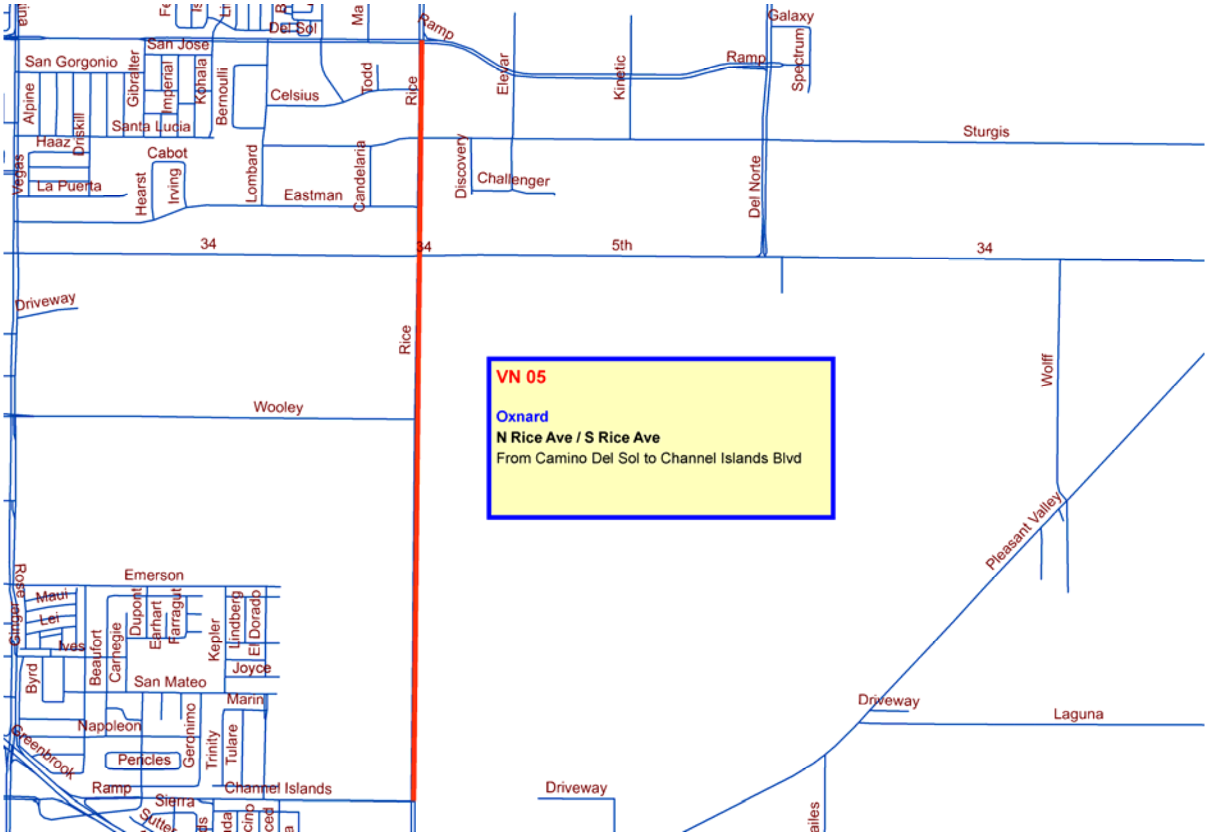

Figure 2-25. Arterial speed survey sample VN 05 detail

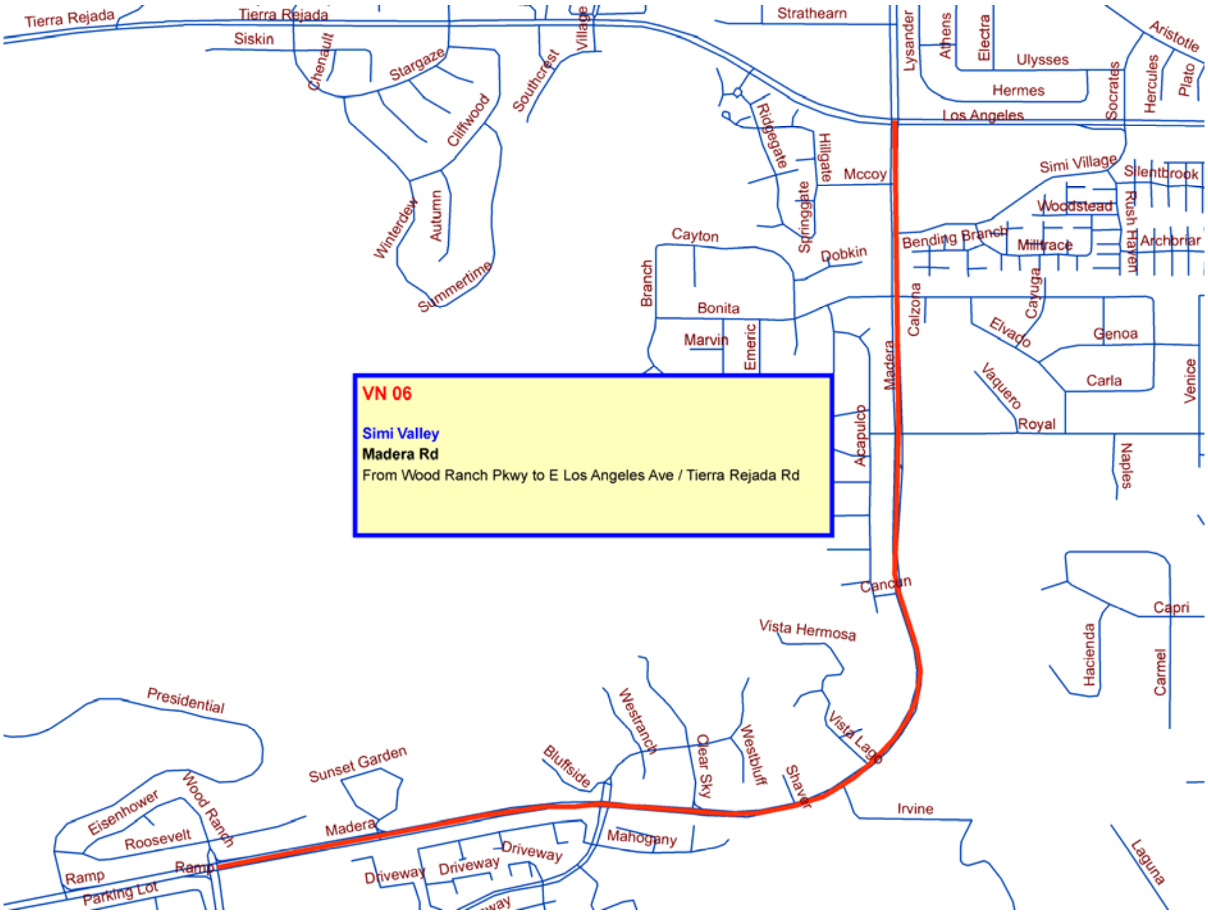

Figure 2-26. Arterial speed survey sample VN 06 detail

2.2 Field Procedures

Introduction

The field procedures were based on the methods and recommendations of Phase I and on the overview presented in the Revised Work Scope. Wiltec, under contract to Dowling Associates, gathered VDF calibration data for selected arterials in each of the 6 SCAG counties (Imperial, Los Angeles, Orange, Riverside, San Bernardino, and Ventura) as discussed above in section 2.1.

Each arterial segment was selected so as to be no more than 2 miles long and to contain no more than 5 signals. These limits were set as to ensure that adequate resources were available to conduct surveys in each of the counties. Arterial segments were defined so that a study vehicle can make a round-trip traverse of the segment about every 15 minutes. Each site was be surveyed four-hour period from 2:00 PM to 6:00 PM.

Preparation

Preparation consisted of the following steps:

1. Jacobs-Carter-Burgess, under subcontract to Dowling Associates, provided preprogrammed GPS units to the speed survey contractor. The units were accompanied by instructions on how to use the units and how to transmit the data to Jacob-Carter-Burgess.

2. Collect volume, speed, and signal timing data for arterials.[1] Jacobs-Carter-Burgess had been collecting these data for the SCAG highway inventory. For those arterials where these data were not yet entered into the highway inventory database, Dowling Associates inferred link characteristics from the existing SCAG network.

3. Dowling Associates in conjunction with Jacobs-Carter-Burgess reviewed data on each selected arterial to obtain facility type, area type, number of through lanes, divided/undivided, speed limits, parking restrictions.

Field operations

1. Wiltec, under contract to Dowling Associates, conducted 24-hour machine counts for each arterial site for the day of the speed surveys. The goal was to install one machine in the middle of each direction of each segment of the arterial; a segment is defined as the stretch of street between two signals. Thus for a one-mile long arterial with 5 signals (making 8 directional segments), there were 8 machines placed to collect counts. The count data were aggregated into 24 one-hour directional counts.

2. The machine counters were installed the day before the speed survey in each arterial segment. The hoses and operation of each machine counter were checked on the day of the speed survey just prior to the start of the speed survey runs. The machines were collected and their data downloaded following the completion of the speed survey runs. Data transmission and proof of count results were completed the following day of the count.

3. Wiltec, the speed survey contractor, conducted a floating car up and down the street for a 4-hour period starting at 2 PM and going to 6 PM (this catches the transition from uncongested to congested operation). The driver was instructed to proceed as follows:

   - Begin the run at 2 PM just before the first identified location on the segment. Beginning and ending points are at intersections, so drivers will begin each run *before* the first intersection of the segment.

[1] Historic volume and speed data will be used to double-check speed and volume data from the survey.

- Complete the run.
- Turn around and begin a run in the reverse direction.
- Continue until the end of the survey period (6 PM).

4. The driver was be instructed to pass as many cars as pass him/her. Each car was equipped with a programmed GPS/recording device to record vehicle position and time during the runs.
5. Drivers recorded the following information:
   - Date
   - Driver name
   - Arterial name
   - Posted speed limit
   - Number of lanes in each direction of travel
   - Location of signals (identify by cross street)
   - Start and end times of run
6. At average speeds ranging from 20 mph to 30 mph (including stops and turnaround times), each survey vehicle was able to obtain 8 – 10 runs for each direction of the arterial over the length of the survey period.

Quality Control and database development

Dowling Associates and Jacobs-Carter-Burgess conducted quality control checks the next day on the GPS data to verify that speeds are within reasonable ranges (e.g. no 70 mph speeds on arterial streets).

3 Database Development and Summary Data Analysis

3.1 Database Development

Arterial speed survey data and PeMS data used to estimate the freeway VDF were put into a single database. It was initially intended that this database would be compatible with the Regional Highway Inventory database. But at the time the data were collected, the Regional Highway Inventory database had not been completed. We therefore entered the data into an Access 2003 database, which can later be exported in a format compatible with the Regional Highway Inventory database.

Database Contents

The following items were included in the database:

- Phase 1 arterial speed and volume data used for VDF estimation in the Phase 1 project
- Speed and volume data from the Phase 2 arterial speed survey.
- PeMS speed and volume data from used to estimate the freeway VDF.

ATSAC data were not available at the time the database was created. SCAG commissioned two ongoing projects to provide ATSAC data, which will be provided separately as part of those projects.

Data and data types in the database are shown in Table 3-1.

Variable	Data type	Source
Link ID	Int	SCAG network
Name	Alphanumeric	SCAG network
A node	Int	SCAG network
B node	Int	SCAG network
N lanes	Int	SCAG network
Capacity	Int	SCAG network
Posted speed	Int	SCAG network
Facility type	Int	SCAG network
Area type	Int	SCAG network
PeMS VDS ID	Int	PeMS
Route number	Int	Arterial or PeMS data
Direction of travel	Int	Arterial or PeMS data
Date	Int	Arterial or PeMS data
Time (hour)	Int	Arterial or PeMS data
Flow	Int	Arterial or PeMS data
Speed	Double	Arterial or PeMS data
% observed	Double	PeMS
Occupancy	Double	PeMS

Table 3-1. Database structure

From the standpoint of proper database design, some of the fields are redundant, as the link ID, A node, and B node can be related to the link database from the SCAG model to get other attributes such as posted speed and number of lanes. But this structure was created in order to provide a stand-alone database that can be easily exported to the Regional Highway Inventory database without reference to other data sources.

Data for VDF estimation were developed from PeMS hourly speed-volume data for the SCAG region. The following were the steps used to produce the freeway VDF estimation data set:

1. Selectively download PeMS hourly speed-volume data for the SCAG region.

2. Filter the data for quality: i.e., an adequate percentage of observed (vs. imputed) values.

3. Aggregate the data according to SCAG time periods, resulting in one observation per time period. The following time period definitions were used: AM peak (0600 – 0900), PM peak (1500 – 1900), midday (0900 – 1500), and night (1900 – 0600).

4. Merge the data with SCAG network data to assign the network data – area type, county, free-flow speed, and capacity – to each PeMS station. Where possible we used the pems_id field in the SCAG link file to match to the PeMS station number; this matched about 65% of the PeMS stations; for the remaining PeMS stations we carried out a manual lookup to identify the link for each station.

PeMS Data

We selected PeMS data using these criteria:

- PeMS stations within the SCAG region (Caltrans Districts 07, 08, and 12)
- Weekdays between 1 April 2007 and 30 September 2007. These date limits were selected to 1) provide the most recent available data, 2) minimize the chance of inclement weather confounding the observations, and 3) ensure good daylight conditions during both peak periods.
- Data points with a minimum of 75% observed. PeMS always imputes data to fill in missing data points. The 75% threshold provides a realistic balance between data quality and quantity.

The number of PeMS stations matching these criteria are shown in Table 3-2.

Area type	**County**						**Total**
	Imperial	Los Angeles	Orange	Riverside	San Bernardino	Ventura	
Core	0	0	0	0	0	0	0
CBD	0	1	3	0	0	0	4
Urban bus. dist.	0	205	124	11	26	5	371
Urban	0	394	164	27	50	10	645
Suburban	0	128	76	60	70	23	357
Rural	0	5	5	0	1	0	11
Mountain	0	0	0	0	10	0	10
Total	0	733	372	98	157	38	1,398

Table 3-2. Number of PeMS stations by area type and county

The hourly PeMS data were aggregated into the four SCAG time periods. Data for an individual time period for a given day were not considered complete unless each PeMS hourly observation for that time period met the 75% observed threshold. The number of time period observations by area type and county are shown in Table 3-3.

Area type	County						Total
	Imperial	Los Angeles	Orange	Riverside	San Bernardino	Ventura	
Core	0	0	0	0	0	0	0
CBD	0	332	1,102	0	0	0	1,434
Urban bus. dist.	0	72,356	45,800	3,580	8,813	1,087	131,636
Urban	0	143,369	59,798	9,456	18,199	3,657	234,479
Suburban	0	41,016	21,891	19,969	23,528	9,230	115,634
Rural	0	1,774	1,336	0	395	0	3,505
Mountain	0	0	0	0	3,729	0	3,729
Total	0	258,847	129,927	33,005	54,664	13,974	490,417

Table 3-3. Number of PeMS time period observations by area type and county

Arterial Data

Arterial data consist of floating car speed run data plus associated traffic counts from the Phase 1 and 2 speed surveys. A total of 8 arterial segments were surveyed in Phase 1 and 24 arterial segments in Phase 2. A complete list of the Phase 1 and 2 samples is shown in Table 3-4.

Phase	City	Location		
		Street	From	To
1	Marina Del Rey	Lincoln Blvd	Washington Blvd.	Venice Blvd
1	Los Angeles	Beverly Blvd	Robertson Blvd	La Cienega Blvd
1	Los Angeles	1st St	Gage Ave	Ford Blvd
1	Glendale, Los Angeles	Verdugo Rd	N Shasta Cir	Colorado Blvd
1	Los Angeles	Western Ave	W 120th St	W 111th St
1	Los Angeles	San Vicente Blvd	Curson Ave	Redondo Blvd
1	Los Angeles	Sunset Blvd	N La Brea Ave	N Cherokee Ave
1	Los Angeles	Aviation Blvd	W 135th St	W 120th St
2	Calexico	W Birch St (SR98)	Imperial Ave	Andrade Ave
2	Compton	E Rosecrans Ave	N Willow brook Ave	Atlantic Ave
2	La Puente / West Covina	N Hacienda Blvd (SR39)	N Unruh Ave	E Cameron Ave
2	Long Beach	E Anaheim St	Junipero Ave	Clark Ave
2	La Habra Heights	N Harbor Blvd	Fullerton Rd	Orange County Line
2	La Puente / Hacienda Heights	7th Ave	Valley Blvd	Palm Ave
2	Castaic	Henry Mayo Dr (SR126)	Chiquito Canyon Rd	Pico Canyon Rd
2	E of Tustin	E Santiago Canyon Rd	Jamboree Rd	SR241 on ramp
2	Anaheim	W Broadway Ave	N Euclid St	S Harbor Blvd
2	Fullerton	N State College Blvd	Yorba Linda Blvd	Imperial Hwy (SR90)
2	Fountain Valley / Costa Mesa	Talbert Ave	Brookhurst	Harbor Blvd
2	La Habra	Hacienda Rd (SR39)	W Whittier Blvd	Citrus St
2	Riverside	Market St	SR 60 (EB off)	University Ave
2	Riverside	Van Buren Blvd	Victoria Ave	Mockingbird Canyon Rd
2	Perris	N Perris Blvd	E 11th St	Nuevo Rd
2	Riverside	Washington St	Overlook Pkwy	Golden Star Ave
2	San Bernardino	University Pkwy	Hallmark Pkwy	Northpark Blvd
2	Bloomington	Cedar Ave	Bloomington Ave	W Rialto Ave
2	Chino Hills	Central Ave	Schaefer Ave	SB on-ramp to NB SR71
2	Rialto	E Rialto Ave	Acacia Ave	Rancho Ave
2	Moorpark	Moorpark Rd	Read Rd	Tierra Rejada Rd
2	Camarillo	Pleasant Valley Rd	Springville Rd	S Lewis Rd
2	Oxnard	N Rice Ave	Camino Del Sol	Channel Islands Blvd
2	Simi Valley	Madera Rd	Wood Ranch Pkwy	E Los Angeles Ave / Tierra Rejada Rd

Table 3-4. Phase 1 and 2 speed survey sample segments

3.2 Survey Data Tabulations

We tabulated the speed data by facility type, county, and area type. Freeway data were tabulated for AM and PM peak periods only. A summary of the results is presented in Table 3-5 through Table 3-7 below.

Although we computed standard errors for the estimated mean speeds for all facility types, the reader should be aware that the limited sample sizes for principal and minor arterials do not allow any meaningful conclusions to be drawn. In particular, the Phase 2 sample was biased toward arterial segments for which the network data indicated high levels of congestion. Hence, the Phase 1 and 2 samples taken together cannot be regarded as representative of conditions on the SCAG arterial network as a whole.

Freeway speeds show some significant differences between different area types and counties. But for the most part, these differences appear to be rather small. The largest differences appear to be within Orange County, where average peak-period speeds range from 56 – 57 mph for CBD and Urban Business District area types to 63 – 65 mph for Suburban and Rural area types.

County	Area type	N obs	Mean	Std err
Imperial	No data available			
Los Angeles	Core	0	NA	NA
	CBD	246	60.74	0.56
	Urban business district	55,308	57.24	0.06
	Urban	110,624	55.89	0.05
	Suburban	33,629	62.46	0.06
	Rural	1,598	65.39	0.15
	Mountain	0	NA	NA
Orange	Core	0	NA	NA
	CBD	946	55.83	0.39
	Urban business district	35,251	56.61	0.08
	Urban	47,321	58.16	0.06
	Suburban	16,586	62.64	0.08
	Rural	1,002	64.85	0.40
	Mountain	0	NA	NA
Riverside	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	2,751	59.17	0.21
	Urban	7,223	59.66	0.15
	Suburban	15,741	58.28	0.10
	Rural	0	NA	NA
	Mountain	0	NA	NA
San Bernardino	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	6,757	61.25	0.11
	Urban	14,084	63.78	0.06
	Suburban	18,526	63.18	0.07
	Rural	308	63.57	0.36
	Mountain	2,969	64.15	0.22
Ventura	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	1,084	65.33	0.24
	Urban	2,906	64.81	0.09
	Suburban	7,228	64.51	0.07
	Rural	0	NA	NA
	Mountain	0	NA	NA

Table 3-5. Average speeds by county and area type, freeways

County	Area type	N obs	Mean	Std err
Imperial	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	1	8.52	2.92
	Urban	116	24.04	0.46
	Suburban	78	27.21	0.59
	Rural	0	NA	NA
	Mountain	0	NA	NA
Los Angeles	Core	0	NA	NA
	CBD	32	18.31	0.76
	Urban business district	177	22.89	0.36
	Urban	319	22.42	0.27
	Suburban	307	51.71	0.41
	Rural	0	NA	NA
	Mountain	0	NA	NA
Orange	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	209	30.40	0.38
	Urban	0	NA	NA
	Suburban	332	34.44	0.32
	Rural	0	NA	NA
	Mountain	0	NA	NA
Riverside	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	190	27.02	0.38
	Urban	0	NA	NA
	Suburban	284	35.15	0.35
	Rural	0	NA	NA
	Mountain	0	NA	NA
San Bernardino	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	0	NA	NA
	Urban	99	31.71	0.57
	Suburban	100	35.49	0.60
	Rural	0	NA	NA
	Mountain	0	NA	NA
Ventura	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	0	NA	NA
	Urban	61	30.31	0.70
	Suburban	371	33.16	0.30
	Rural	0	NA	NA
	Mountain	0	NA	NA

Table 3-6. Average speeds by county and area type, principal arterial

County	Area type	N obs	Mean	Std err
Imperial	No observations			
Los Angeles	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	111	29.88	0.52
	Urban	150	24.42	0.40
	Suburban	8	33.38	2.04
	Rural	0	NA	NA
	Mountain	0	NA	NA
Orange	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	0	NA	NA
	Urban	129	24.13	0.43
	Suburban	0	NA	NA
	Rural	0	NA	NA
	Mountain	0	NA	NA
Riverside	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	0	NA	NA
	Urban	0	NA	NA
	Suburban	180	42.85	0.49
	Rural	0	NA	NA
	Mountain	0	NA	NA
San Bernardino	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	0	NA	NA
	Urban	324	31.72	0.31
	Suburban	243	20.31	0.29
	Rural	0	NA	NA
	Mountain	0	NA	NA
Ventura	Core	0	NA	NA
	CBD	0	NA	NA
	Urban business district	0	NA	NA
	Urban	0	NA	NA
	Suburban	62	40.37	0.81
	Rural	0	NA	NA
	Mountain	0	NA	NA

Table 3-7. Average speeds by county and area type, minor arterial

4 Arterial VDF Estimation

4.1 Introduction

This section presents the initial estimates for the arterial volume-delay functions. Section 2 discusses data sources and preparation. Section 3 discusses estimation results.

The existing VDFs in the SCAG model consist of Akcelik and BPR curves. Currently SCAG is using a modified Akcelik curve with a specified minimum length. Our experience with using demand models with feedback loops leads us to believe that BPR curves are preferable to Akeclik curves for stability of convergence in the assignment step. We therefore carried out our VDF estimates for BPR curves.

4.2 Data Sources

Data for VDF estimation were developed from Phase 1 and Phase 2 arterial speed and volume surveys. The following were the steps used to produce the arterial VDF estimation data set:

1. Develop a sample of 24 arterial segments to be surveyed for Phase 2.

2. Carry out the surveys for Phase 2.

3. Merge the Phase 2 survey data with SCAG network data to get link node IDs, area type, facility type, posted speed, free-flow speed, and capacity for each link.

4. Aggregate the Phase 2 data into hourly summary data with speeds and flows for each hour.

5. Merge the Phase 2 data with Phase 1 data.

Locations for the Phase 1 and 2 arterial speed surveys are shown in Table 4-1 on the next page. Maps of each section appear in section 2.1 above.

Data points for VDF estimation consisted of hourly averages for individual links. The number of link hourly observations by county, area type, and facility type are shown in Table 4-2. Table 4-3 summarizes these observations by area type and facility type only.

Phase	City	Location		
		Street	From	To
1	Marina Del Rey	Lincoln Blvd	Washington Blvd.	Venice Blvd
1	Los Angeles	Beverly Blvd	Robertson Blvd	La Cienega Blvd
1	Los Angeles	1st St	Gage Ave	Ford Blvd
1	Glendale, Los Angeles	Verdugo Rd	N Shasta Cir	Colorado Blvd
1	Los Angeles	Western Ave	W 120th St	W 111th St
1	Los Angeles	San Vicente Blvd	Curson Ave	Redondo Blvd
1	Los Angeles	Sunset Blvd	N La Brea Ave	N Cherokee Ave
1	Los Angeles	Aviation Blvd	W 135th St	W 120th St
2	Calexico	W Birch St (SR98)	Imperial Ave	Andrade Ave
2	Compton	E Rosecrans Ave	N Willow brook Ave	Atlantic Ave
2	La Puente / West Covina	N Hacienda Blvd (SR39)	N Unruh Ave	E Cameron Ave
2	Long Beach	E Anaheim St	Junipero Ave	Clark Ave
2	La Habra Heights	N Harbor Blvd	Fullerton Rd	Orange County Line
2	La Puente / Hacienda Heights	7th Ave	Valley Blvd	Palm Ave
2	Castaic	Henry Mayo Dr (SR126)	Chiquito Canyon Rd	Pico Canyon Rd
2	E of Tustin	E Santiago Canyon Rd	Jamboree Rd	SR241 on ramp
2	Anaheim	W Broadway Ave	N Euclid St	S Harbor Blvd
2	Fullerton	N State College Blvd	Yorba Linda Blvd	Imperial Hwy (SR90)
2	Fountain Valley / Costa Mesa	Talbert Ave / MacArthur Blvd	Brookhurst	Harbor Blvd
2	La Habra	Hacienda Rd / Glendora Ave (SR39)	W Whittier Blvd	Citrus St
2	Riverside	Market St	SR 60 (EB off)	University Ave
2	Riverside	Van Buren Blvd	Victoria Ave	Mockingbird Canyon Rd
2	Perris	N Perris Blvd	E 11th St	Nuevo Rd
2	Riverside	Washington St	Overlook Pkwy	Golden Star Ave
2	San Bernardino	University Pkwy	Hallmark Pkwy	Northpark Blvd
2	Bloomington	Cedar Ave	Bloomington Ave	W Rialto Ave
2	Chino Hills	Central Ave	Schaefer Ave	SB on-ramp to NB SR71
2	Rialto	E Rialto Ave	Acacia Ave	Rancho Ave
2	Moorpark	Moorpark Rd	Read Rd	Tierra Rejada Rd
2	Camarillo	Pleasant Valley Rd	Springville Rd	S Lewis Rd
2	Oxnard	N Rice Ave	Camino Del Sol	Channel Islands Blvd
2	Simi Valley	Madera Rd	Wood Ranch Pkwy	E Los Angeles Ave / Tierra Rejada Rd

Table 4-1. Arterial speed sample segments

County	Area type	Facility type		Total
		Principal arterial	Minor arterial	
Imperial	Urban	27	—	27
	Suburban	18	—	18
Imperial total		45	—	45
Los Angeles	Central business district	32	—	32
	Urban business district	128	27	155
	Urban	117	67	184
	Suburban	41	8	49
Los Angeles total		318	102	420
Orange	Urban business district	51	—	51
	Urban		28	28
	Suburban	58	—	58
Orange total		109	28	137
Riverside	Urban business district	42	—	42
	Suburban	63	36	99
Riverside total		105	36	141
San Bernardino	Urban	25	72	97
	Suburban	28	50	78
San Bernardino total		53	122	175
Ventura	Urban	19	—	19
	Suburban	77	10	87
Ventura total		96	10	106
All counties total		726	298	1,024

Table 4-2. Number of hourly link observations by county, area type, and facility type

Area type	Facility type		Total
	Principal arterial	Minor arterial	
Central business district	32		32
Urban business district	221	27	248
Urban	188	167	355
Suburban	285	104	389
Total	726	298	1,024

Table 4-3. Number of hourly link observations by area type and facility type

4.3 Assessment of Coded Capacities and Free-Flow Speeds

Phase 2 speed data were merged with count data for individual segments. The hourly count for each segment was attached to all speed observations for that segment. Speeds were then averaged over each hour. SCAG network data were attached to the speed and count data to get facility type, area type, free-flow speed, and capacity.

We first plotted out observed speeds and traffic volumes vs. SCAG values for free-flow speeds and volumes. Figure 4-1 and Figure 4-2 show the results. It is apparent that a significant number of observations for both principal and minor arterials fall above the coded free-flow speeds and capacities in the SCAG network. These results suggest that it may be worthwhile to review arterial free-flow speeds and capacities on the SCAG network and perhaps adjust them upwards.

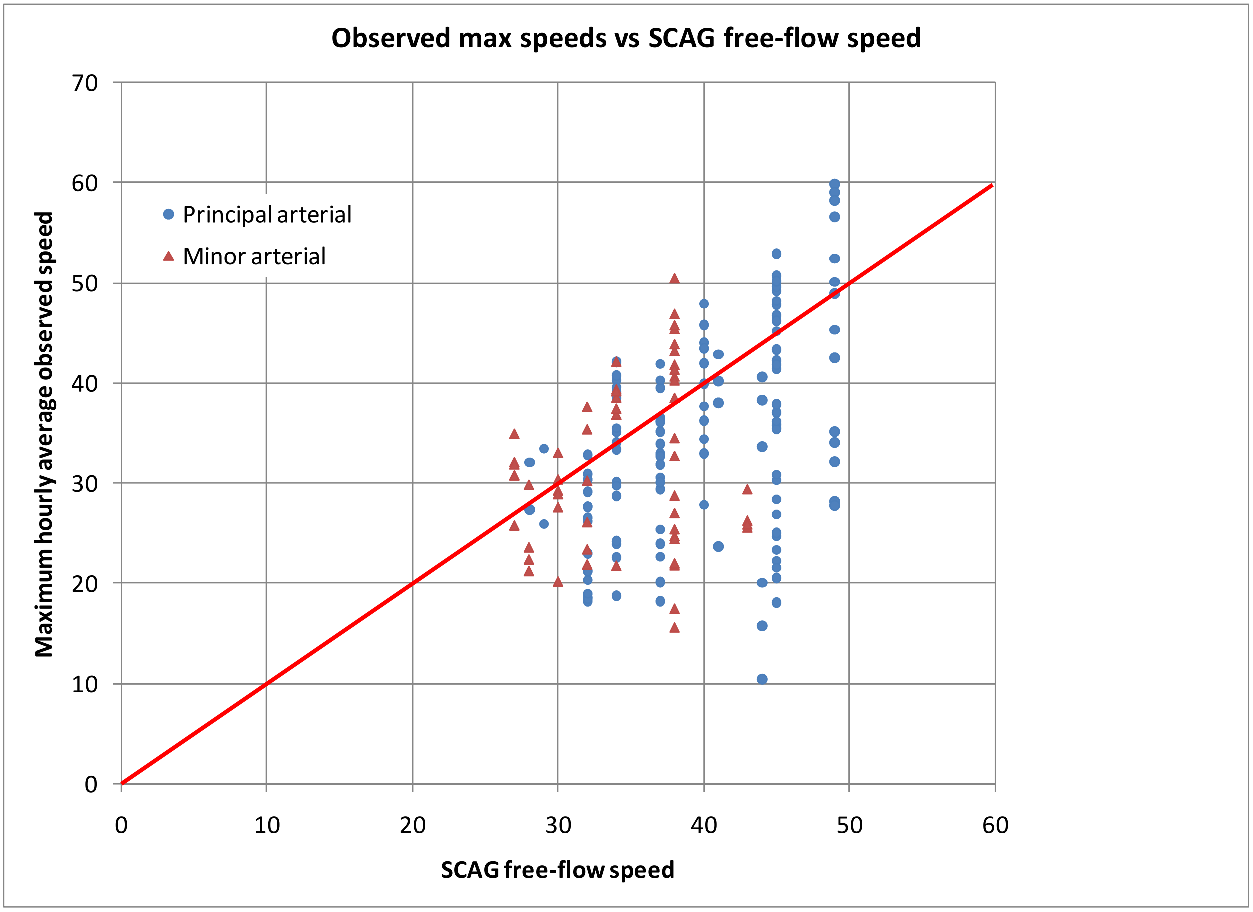

Figure 4-1. Maximum observed hourly speed vs. SCAG free-flow speed by segment

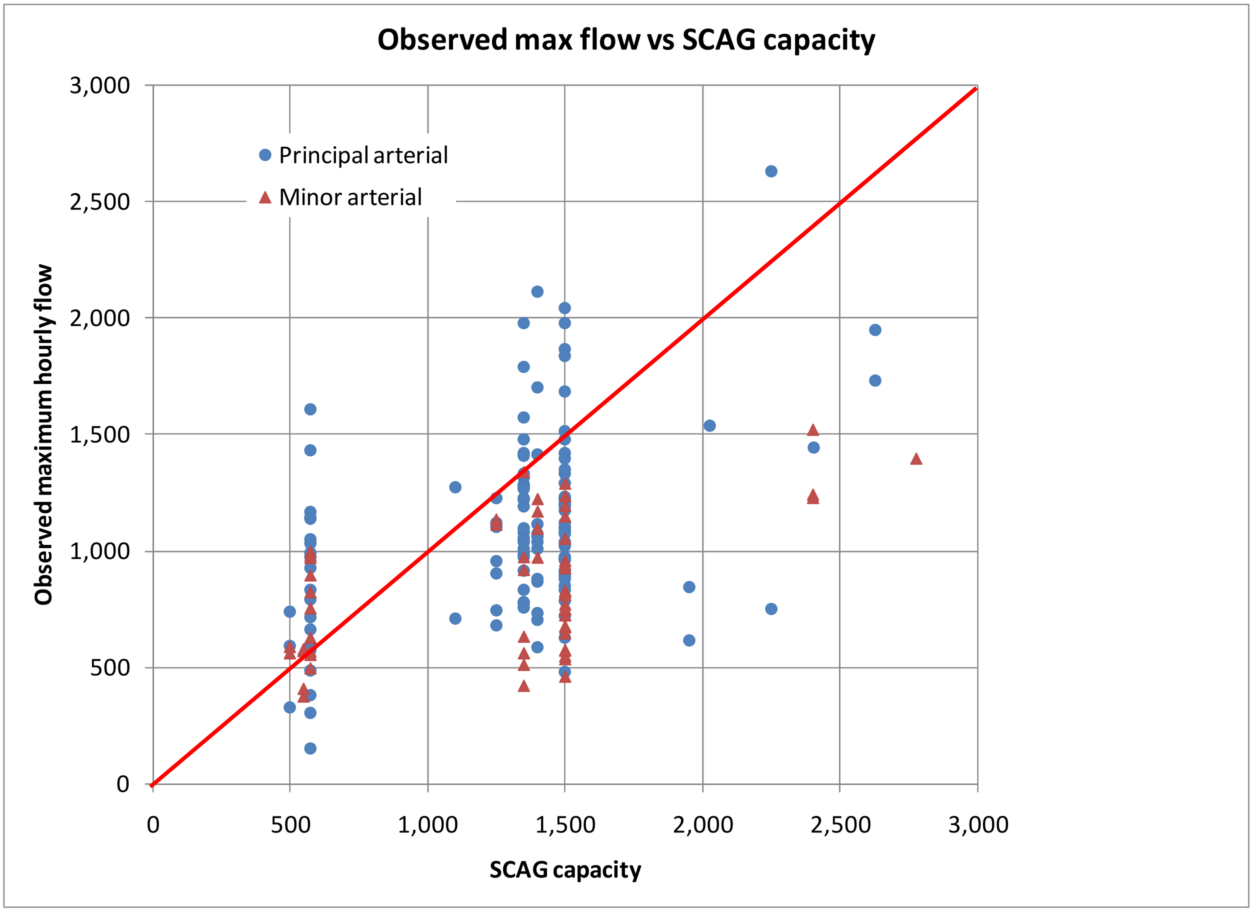

Figure 4-2. Maximum observed hourly flow vs. SCAG capacity by segment

We then proceeded to examine the coded free-flow speeds and capacities by facility type and area type. Figure 4-3 through Figure 4-6 examine the data by area type.

As shown in Figure 4-3, the principal arterials in central business districts (CBD) (AT 2) exhibit typical two-regime behavior, a cluster of uncongested points, and a second cluster of congested points, with a few transition points between the two regimes. The SCAG coded capacities and free-flow speeds of the Principal Arterials within a CBD appear to be about right. The uncongested points center around 100% of the coded free-flow speed. All observations are equal to or less than a v/c ratio of 1.33. (The SCAG assignment process boosts the computed v/c ratio by 1.33 before computing the travel time).

As shown in Figure 4-4, the urban business district (AT 3) observations show a cloud of points with lots of transition points. The SCAG coded free-flow speeds for Principal Arterials within an Urban Business District appear to be about right. The SCAG coded free-flow speeds for Minor Arterials appear to be about 10% low. The capacities of both the Principal and the Minor Arterials appear to be about 20% to 30% low, when compared to the observations for arterials in an Urban Business District.

As shown in Figure 4-5, the urban area (AT 4) observations show a cloud of points with lots of transition points. The SCAG coded free-flow speeds and capacities for both types of arterials within an Urban Area appear to be about right. The uncongested points appear to cluster appear to center on the speed ratio of 1.00. The observed flow rates are all below capacity.

As shown in Figure 4-6, the suburban area (AT 5) observations show a cloud of points with lots of transition points. A large proportion of the observations are at v/c ratios in excess of 1.5. It appears that while the SCAG coded free-flow speeds for both arterial types are reasonable, the capacities for both arterial types within a suburban area are underestimated by 33% to 50%.

Table 4-4 summarizes arterials with apparently unrealistic observed peak-hour volume/capacity ratios.

Conclusions:

1. The coded free-flow speeds in the SCAG network for principal and minor arterials in area types 2-5 appear to be satisfactory.

2. The coded capacities in the SCAG network for principal and minor arterials in area types 2, and 4 appear to be satisfactory.

3. The coded capacities in the SCAG network for principal and minor arterials in area types 3, and 5 appear to be 20% to 50% low, and should be re-examined during the vdf testing phase of the project.

4. The coded capacities for principal arterials in suburban areas (AT 5) appear to be particularly low, when compared to peak period counts. There were four cases where the counted volumes exceed 2.5 times the coded capacity.

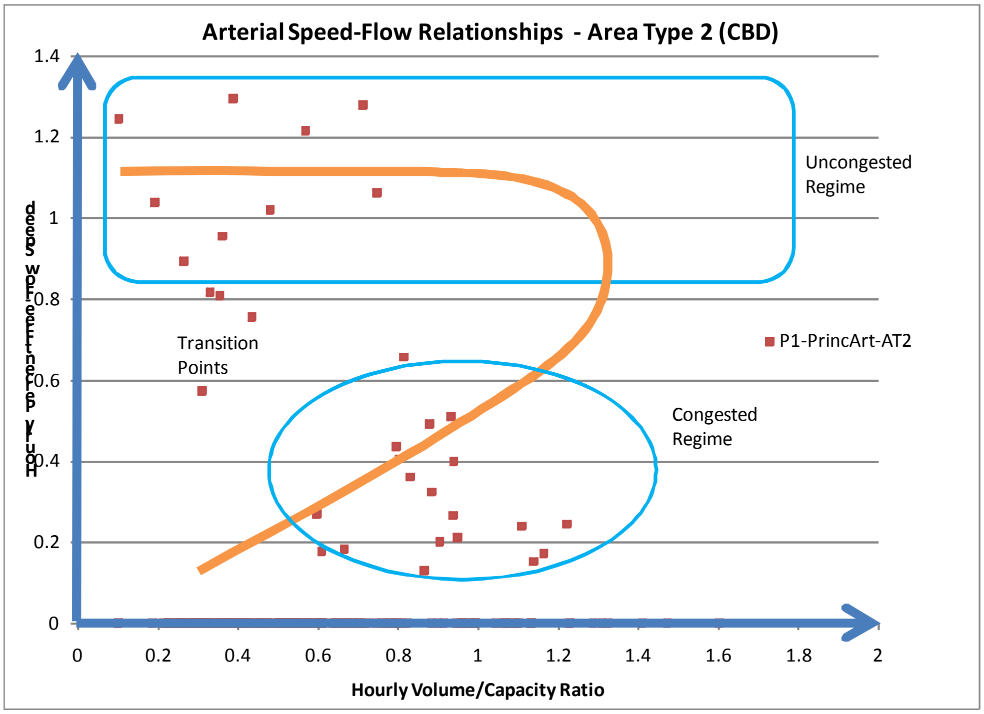

Figure 4-3. Speed-flow relationships, principal arterials, central business district

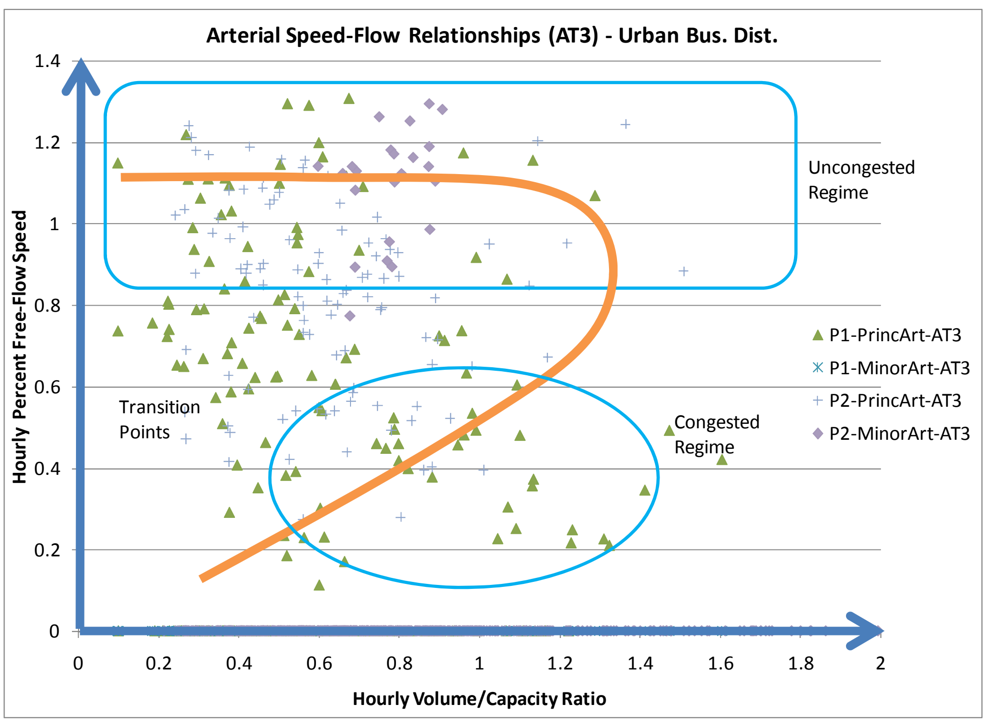

Figure 4-4. Speed-flow relationships, principal and minor arterials, urban business district

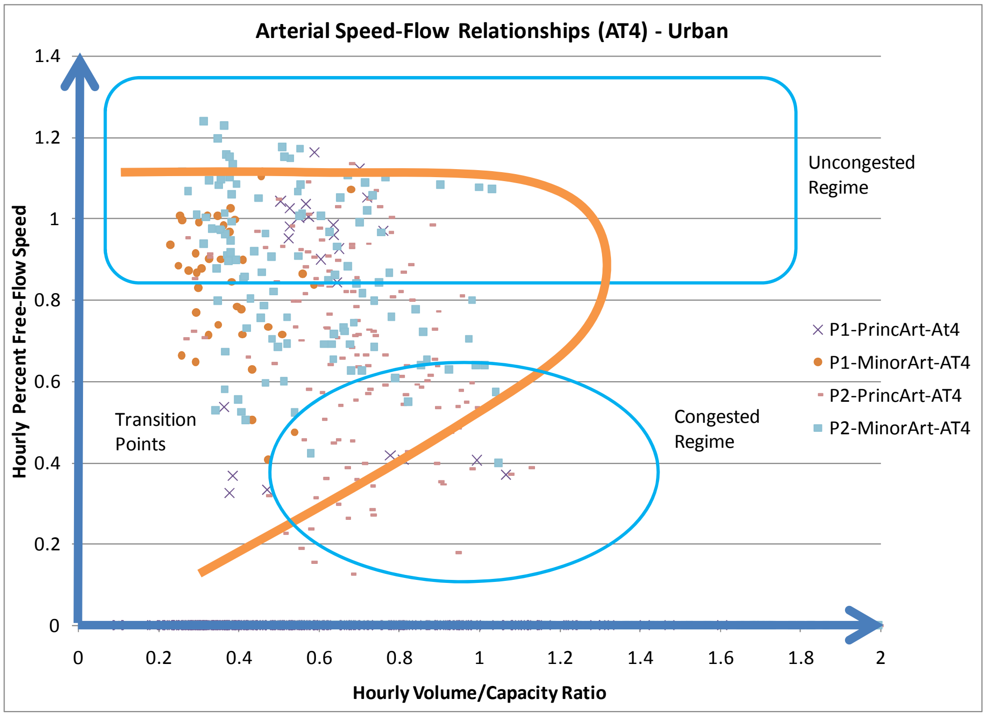

Figure 4-5. Speed-flow relationships, principal and minor arterials, urban

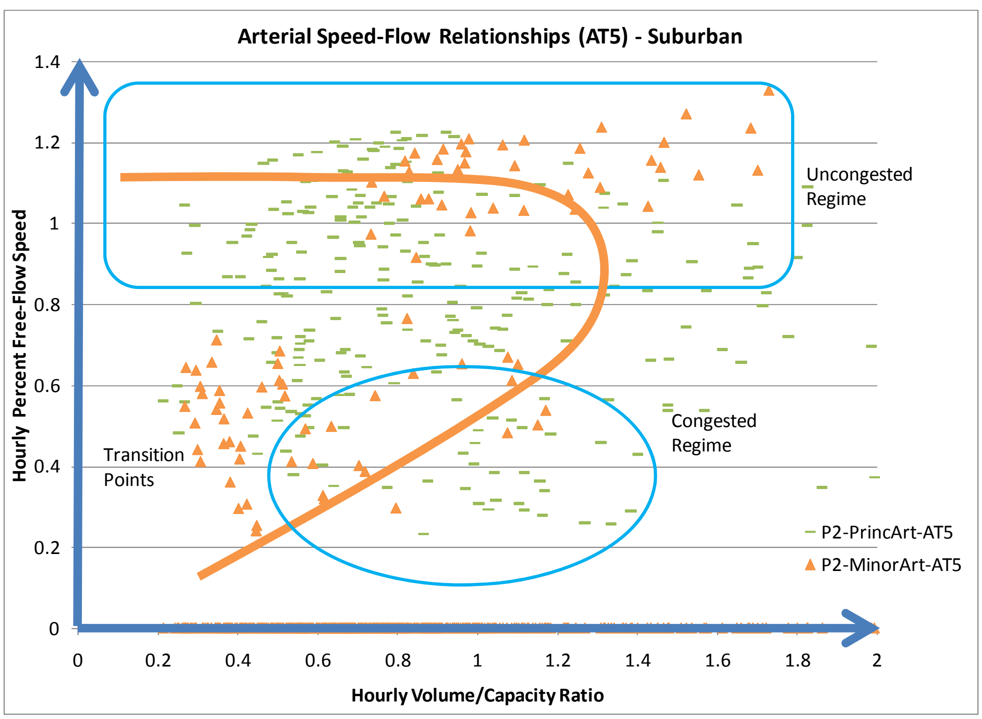

Figure 4-6. Speed-flow relationships, principal and minor arterials, suburban

Segment	Street	From	To	Peak Hour Count (vph/ln)	Computed V/C Ratio
212206	Pleasant Valley Rd	S Lewis Rd	Dawson Dr	1612	2.80
212204	Pleasant Valley Rd	Dawson Dr	E 5th St	1436	2.49
211906	Central Ave	SR 71 NB on ramp	Fairfield Ranch Rd	1171	2.03
212201	Pleasant Valley Rd	Dawson Dr	S Lewis Rd	1146	1.99
210805	E Santiago Canyon Rd	SR 241 NB on-ramp	SR 241 SB on-ramp	1142	1.98
211911	Central Ave	Fairfield Ranch Rd	SR 71 NB on ramp	1050	1.82
211909	Central Ave	El Prado Rd	Fairfield Ranch Rd	1035	1.80
211504	Washington St	Saddleback Rd	Hermosa Dr	994	1.72
211201	Hacienda Rd (SR39)	Russell St	Citrus St	990	1.72
211202	Hacienda Rd (SR39)	W Whittier Blvd	Russell St	978	1.70
211505	Washington St	Bradley St	Hermosa Dr	978	1.70
211502	Washington St	Golden Star	Saddleback Rd	968	1.68
211905	Central Ave	Fairfield Ranch Rd	El Prado Rd	927	1.61
212102	Moorpark Rd	Tierra Rejada Rd	Read Rd	893	1.55
211108	Talbert Ave	Euclid	Ward St	1056	1.50

Note: All arterials in this table happen to be 2-lane principal or minor arterials (one-lane each direction) in Area Type 5, except for Talbert Avenue, which is 4 lanes (two in each direction) in Area Type 3. Thus problem appears to be with coded capacities of 2-lane principal arterials in suburban area (AT 5).

Table 4-4. Arterials with unrealistic peak-hour v/c ratios

4.4 VDF Estimation

The selection of a recommended volume-delay function for arterials was a multi-step process.

Data Filtering For Unreliable Points

- The speed-flow observations were reviewed and unreliable data pulled from the data set according to the following criteria
- All speed estimates based on a single observation were eliminated.
- For the remaining speed estimates, we calculated the standard error of the estimate. The standard error of the estimate is computed as follows:

$$SE = \sqrt{\frac{s^2}{n}}$$

where s^2 is the variance of the speed values for the hour, and n is the number of observations.

- We then computed the coefficient of variation (CV) for each speed estimate. The coefficient of variation is the standard error of the estimate divided by the value of the estimate. Hence, for an estimated speed of 30 mph with a coefficient of variation of 0.10, the standard error would be +/- 3 mph.

- All observations with a CV greater than 0.10 were filtered out.

Figure 4-7 shows a plot of the phase 1 and phase 2 hourly speed-flow observations for all arterial types and all area types after the filtering. A total of 915 observations are displayed for principal and minor arterials in Central Business Districts (AT2), Urban Business Districts (AT3), Urban areas (AT4), and Suburban areas (AT5). The vertical axis is the ratio of the observed hourly average speed to the SCAG network coded free-flow speed for each directional segment of each arterial. The horizontal axis is the ratio of the observed hourly volume to the SCAG network coded capacity for each directional segment of each arterial.

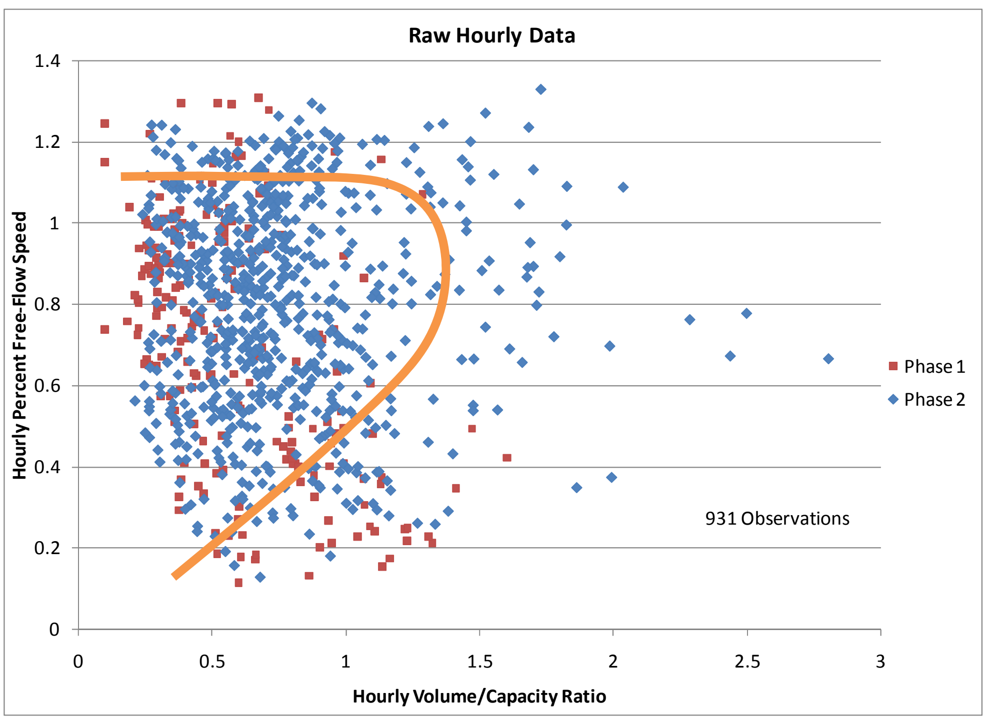

Figure 4-7. Speed-flow observations, all data (hourly)

Directional segments in the data set ranged from 184 feet to 7,970 feet in length. The mean observed hourly speeds ranged from 3.7 mph to 60.0 mph. The mean hourly volumes per lane ranged from 89 to 1612 vph/lane.

The orange curve shows the expected clustering pattern of points based on traditional studies. As can be seen, the observations make a fairly uniform cloud with no obvious patterns. This is because the plot includes observations from both the uncongested and the congested regimes on the arterials. The plot also includes a large number of transition points when the arterial is transitioning between the congested and uncongested regimes. The result is a cloud of points with no observed patterns.

Identification of Uncongested Regime Points

The data were then reviewed to identify the points falling within the uncongested regime of the arterials. These are usually high speed observations within +/- 20% of the free-flow speed where travel times do not vary significantly between floating car runs. For this case the coefficient of variation for travel time was computed and used to identify low variance points where travel times are very stable. The coefficient of travel time was used because it is more sensitive to the variations in travel time at low speeds typical of congested conditions.

The resulting observations of uncongested conditions are shown in Figure 4-8.

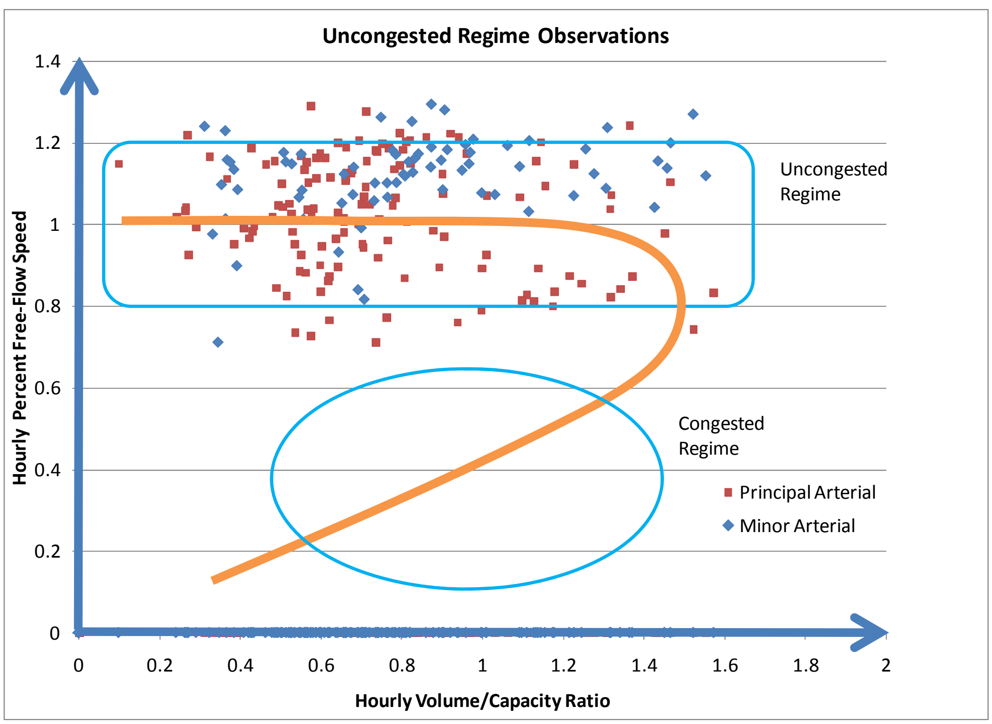

Figure 4-8. Speed-flow observations for uncongested conditions (hourly)

Recommended VDF Hourly Flows

The SCAG BPR VDF was compared to the observed uncongested hourly observations in Figure 4-8. The results are shown in Figure 9. As can be seen the default SCAG BPR curve tends to drop too soon, compared to the field observations. A BPR curve fitted to the data however would be completely flat until a v/c ratio of 1.6 was reached. Consequently a compromise curve is recommended that comes closer to the observed data but still drops fairly rapidly once a v/c ratio of 1.6 is reached.

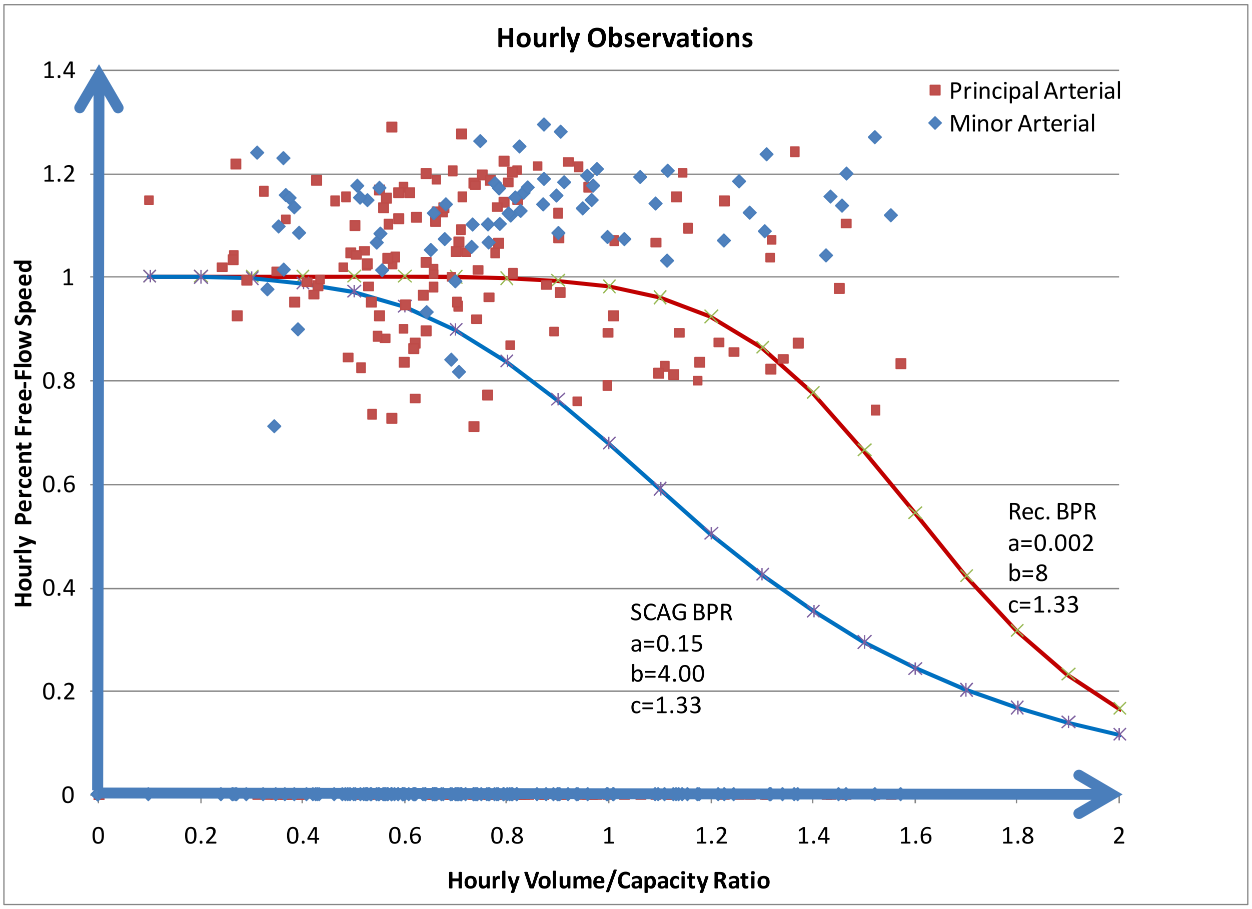

Table 4-5. Recommended BPR curve – hourly flows

The recommended speed-flow curve for arterials (principal and minor) in area types 2-5 (CBD, Urban Business District, Urban, and Suburban) is given below:

$$S = \frac{S_0}{1 + a\left(cx\right)^b}$$

where:

S = congested speed

S_o = free-flow speed

x = volume/capacity ratio

a, b, c = calibration parameters

Our initial recommendations for parameters are shown in Table 4-6.

	Current SCAG	Recommended
Free-Flow Speed		No Change
Capacity		Increase 20% to 50% for Area Types 3 and 5, Especially for 2-lane arterials
a parameter	0.15	0.002
b parameter	4	8
c parameter	1.33	1.33

Table 4-6. Current and recommended speed-flow equation parameters

While no changes are recommended to the network coded free-flow speeds, it is recommended that capacities for principal and minor arterials in area types 3 and 5 be evaluated and possibly increased, especially for two-lane (one lane in each direction) arterials.

Evaluation of Peak Period Speed-Flow Relationships

The previous analyses have focused on hourly speed-flow relationships. However, the SCAG model assigns traffic for two peak periods as well as two off-peak periods:

- AM Peak (6 AM tp 9 AM)
- PM Peak (3 PM to 7 PM)
- Midday (9 AM to 3 PM)
- Night (7 PM to 6 AM)

The hourly data were combined into 4-hour peak mean volumes and mean speeds for the PM peak period. The mean volume/capacity ratio for each 4-hour PM period was computed by computing the mean hourly volume and dividing by the hourly capacity. The data was then replotted. In this case, because we are dealing with the entire peak period it was no longer necessary to constrain the data to uncongested observations only. However, unstable observations (coefficients of variation greater than 20%, and v/c ratios greater than 2.00) were rejected.

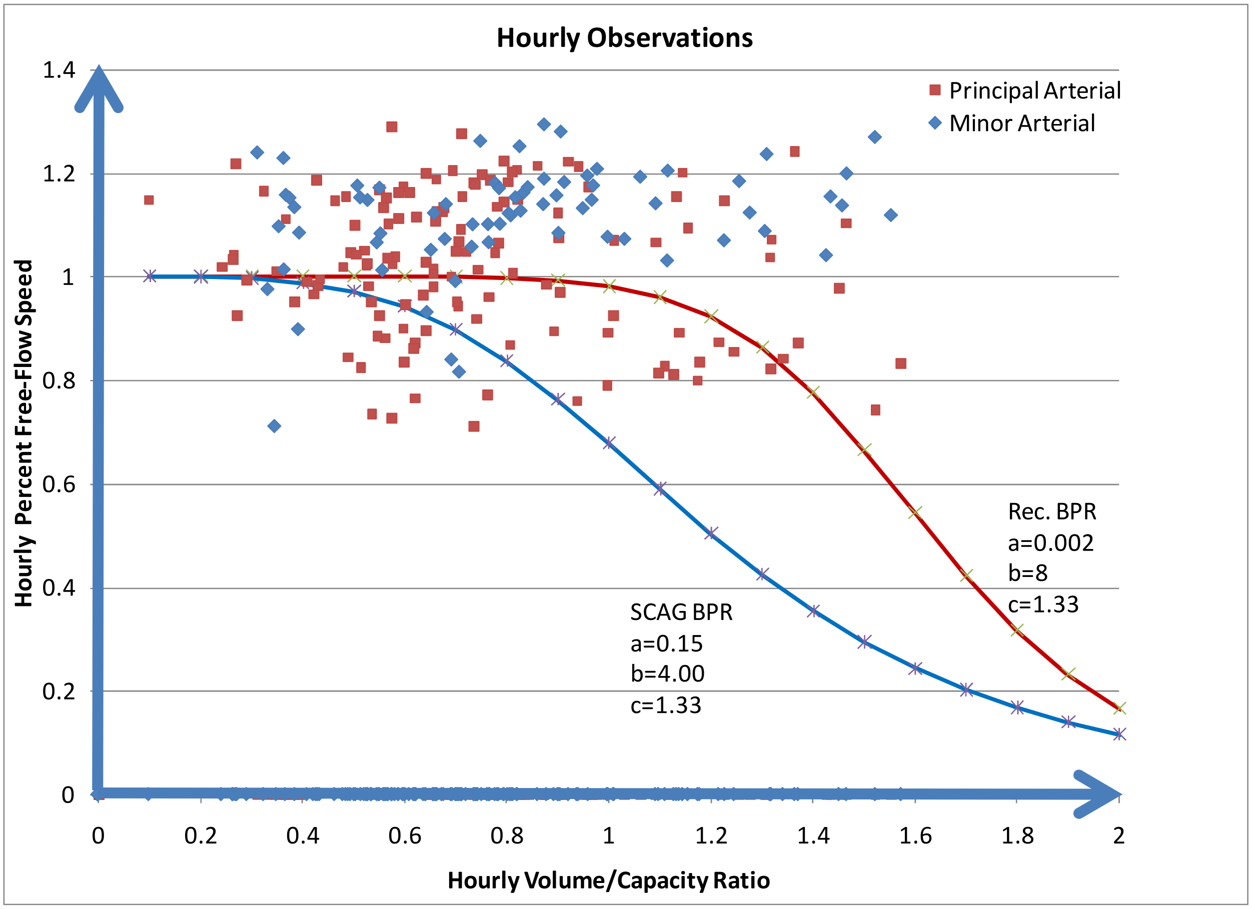

Figure 4-9. Recommended BPR curve – hourly flows

The PM peak 4-hour data are plotted in Figure 4-10. The current SCAG BPR curve and the recommended BPR curve are shown in the figure. The fitted BPR curve that minimizes the squared error between the estimated and observed speeds is also plotted in the figure. The fitted curve however is very flat and less likely to converge quickly. The fitted curve also will result in arterial loadings significantly greater than 1.50 v/c ratio.

The speeds predicted by the current SCAG BPR curve tend to drop more quickly than the data supports.

The recommended BPR curve provides a compromise between fidelity to the data and reasonable model performance. The recommended curve allows more loadings in the v/c 1.00 to 1.50 range, but then drops rapidly for higher v/c ratios.

Figure 4-11 shows how the two curves perform at predicting delay for extreme v/c ratios. The recommended curve matches the data better for v/c ratios under 2.00 and then begins to exceed the delays predicted by the SCAG BPR curve at a 2.30 v/c ratio for the peak period.

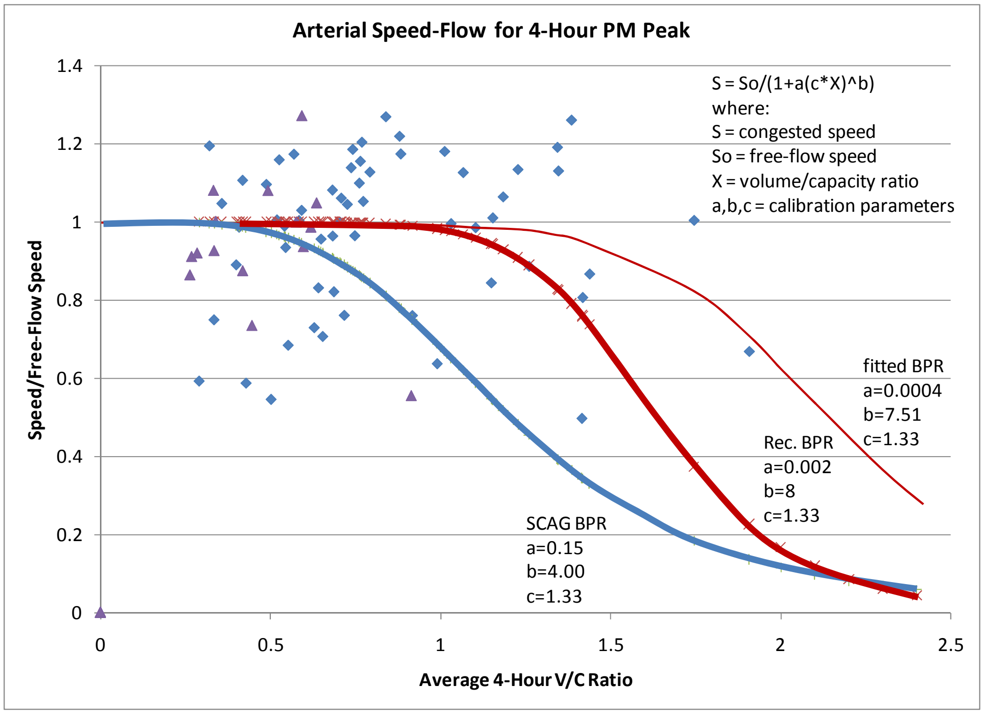

Figure 4-10. Speed-flow relationships for 4 hour PM peak

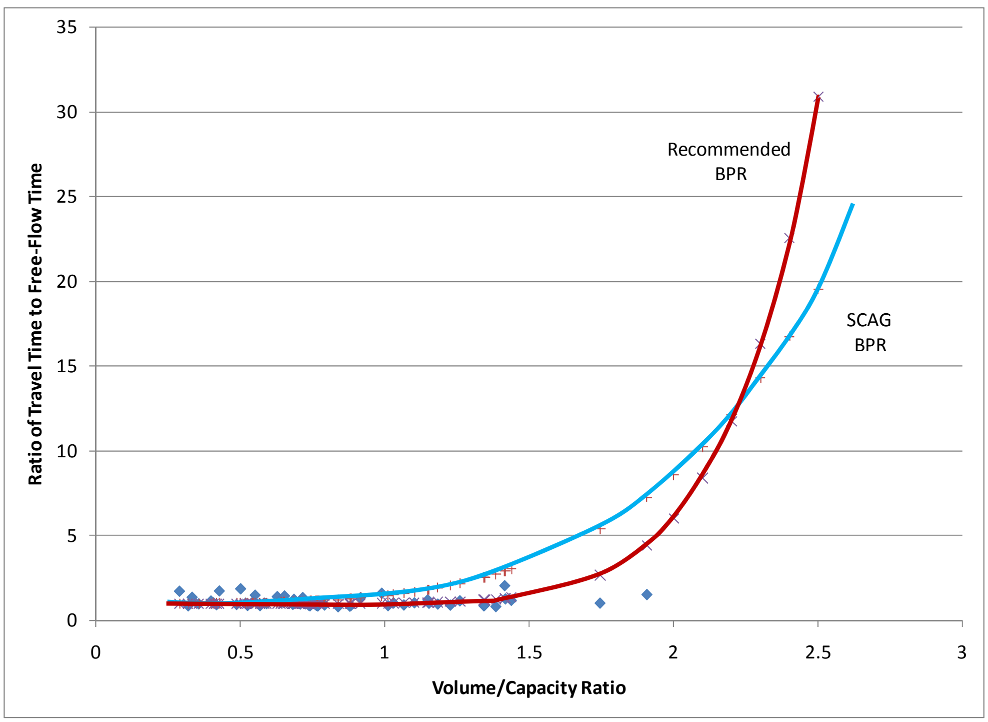

Figure 4-11. Travel time relationship for congested conditions

4.5 Conclusions and Recommendations

The following are our conclusions and recommendations from the initial arterial VDF estimation.

1. Review capacities coded for arterials in area types 3 and 5 (Urban Business District, and Suburban), especially for two-lane arterials (single lane in each direction). They tend to be 20% to 50% low.

2. The coded free-flow speeds arterials appear to match observations reasonably well.

3. Adjust SCAG BPR curve to decline less as volumes approach capacity and to decline faster once volumes exceed 1.33 times capacity.

The analysis of hourly and 4-hour data suggests that the recommended BPR curve is superior for both one-hour and multi-hour peak period assignments.

5 Freeway VDF Estimation

5.1 Introduction

The existing VDFs in the SCAG model consist of Akcelik and BPR curves. Currently SCAG is using a modified Akcelik curve with a specified minimum length. Our experience with using demand models with feedback loops leads us to believe that BPR curves are preferable to Akeclik curves for stability of convergence in the assignment step. We have therefore carried out our VDF estimates for BPR curves.

5.2 Data Preparation and Preliminary Analysis

Data sources are discussed in Section 3 above. In addition to the tabulations in that section, we ran additional tabulations to get a better view of the distribution of speeds and volumes on the PeMS segments selected for VDF estimation. Table 5-1 and Table 5-2 show the observed speed and volume quantiles for the time period data points. Because the number of observations for the Core, CBD, Rural, and Mountain area types are rather small, the standard errors of these quantile estimates are comparatively larger than those for the Urban business district, Urban, and Suburban area types. Nonetheless, the observed 90th, 95th, and 99th percentile speeds are quite similar for most area types (Table 5-1). Similarly, the 99th percentile volumes are quite similar for the Urban business district, Urban, and Suburban area types.

Area type	**Speed quantile (average speed for time period)**					
	50%	**75%**	**85%**	**90%**	**95%**	**99%**
CBD	61	67	68	69	71	73
Urban bus. dist.	65	68	70	70	72	77
Urban	65	68	69	70	71	74
Suburban	66	68	69	70	71	75
Rural	68	70	71	72	73	75
Mountain	68	70	71	72	73	75

Table 5-1. Observed speed quantiles by area type

Area type	**Volume quantile (vplph average for time period)**					
	50%	**75%**	**85%**	**90%**	**95%**	**99%**
CBD	1,518	1,637	1,684	1,718	1,751	1,792
Urban bus. dist.	1,331	1,539	1,639	1,702	1,799	1,977
Urban	1,327	1,534	1,623	1,686	1,791	1,981
Suburban	1,133	1,442	1,549	1,614	1,709	1,902
Rural	1,057	1,355	1,417	1,497	1,557	1,691
Mountain	906	1,100	1,251	1,311	1,388	1,638

Table 5-2. Observed volume quantiles by area type

5.3 VDF Estimation

Several VDFs were estimated for each area type. In order to avoid confounding the estimates, data points were selected for the free-flow regime. Data points were selected for several levels of minimum ratios of observed to free-flow speeds. VDFs were estimated for the following BPR model:

$$\frac{S}{S_{ff}} = \frac{1}{1 + aVC^b}$$

where

S_{ff} = free-flow speed

S = observed speed

VC = volume/capacity

a, b = parameters to be estimated

The estimates were carried out using the non-linear least-squares estimation routine **`nls`** in R, an open-source data analysis package.[1] The estimated results are shown in Table 5-3; SCAG BPR parameters are also shown for comparison.

Area type	Min speed /ffs	Parameter value		Std error		t-statistics		Std error of residuals	DF
		a	*b*	*a*	*b*	*a*	*b*		
Urban bus. dist.	0.85	0.0088	9.1129	0.0014	1.3951	6.1	6.5	0.0866	104,027
	0.80	0.0473	6.8162	0.0017	0.2432	28.1	28.0	0.0921	109,109
	0.75	0.0813	5.9122	0.0019	0.1361	43.9	43.4	0.0982	112,899
Urban	0.85	0.0429	6.4056	0.0009	0.1323	46.1	48.4	0.0689	184,870
	0.80	0.0734	5.2220	0.0010	0.0732	71.5	71.3	0.0756	194,007
	0.75	0.0982	4.7046	0.0011	0.0546	89.0	86.1	0.0822	200,298
Sub-urban	0.85	0.0432	8.0677	0.0018	0.3082	23.5	26.2	0.0637	102,158
	0.80	0.0729	6.3728	0.0020	0.1521	37.3	41.9	0.0692	105,556
	0.75	0.0958	5.6221	0.0020	0.1079	47.0	52.1	0.0744	107,694
SCAG (all area types)	—	1.16	4.33	—	—	—	—	—	—

Table 5-3. VDF estimates by area type and minimum speed/free-flow speed threshold

The resulting curves for the VDF estimates are plotted against observed data in Figure 5-1 through Figure 5-3 for the Urban business district, Urban, and Suburban area types; the SCAG VDF is also shown for purposes of comparison. The following color key is used for the plots:

[1] R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Color	Data
Blue	Observed data point (time period average of PeMS data)
Green	Fitted VDF, minimum speed/FFS ratio = 0.85
Yellow	Fitted VDF, minimum speed/FFS ratio = 0.80
Purple	Fitted VDF, minimum speed/FFS ratio = 0.75
Red	SCAG BPR curve

Table 5-4. Color key for VDF plots

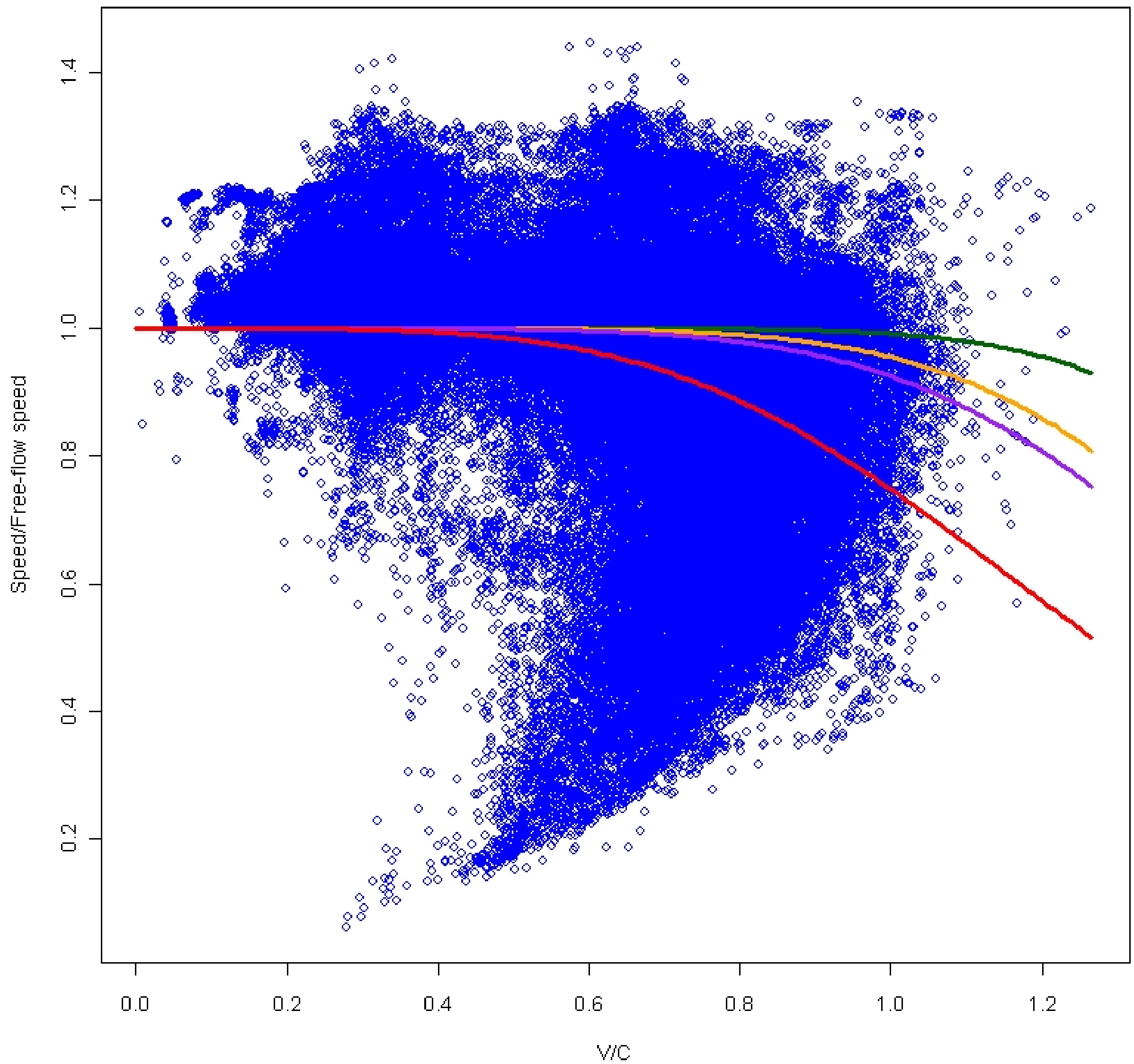

Figure 5-1. VDF curves vs. observed data, urban business district area type

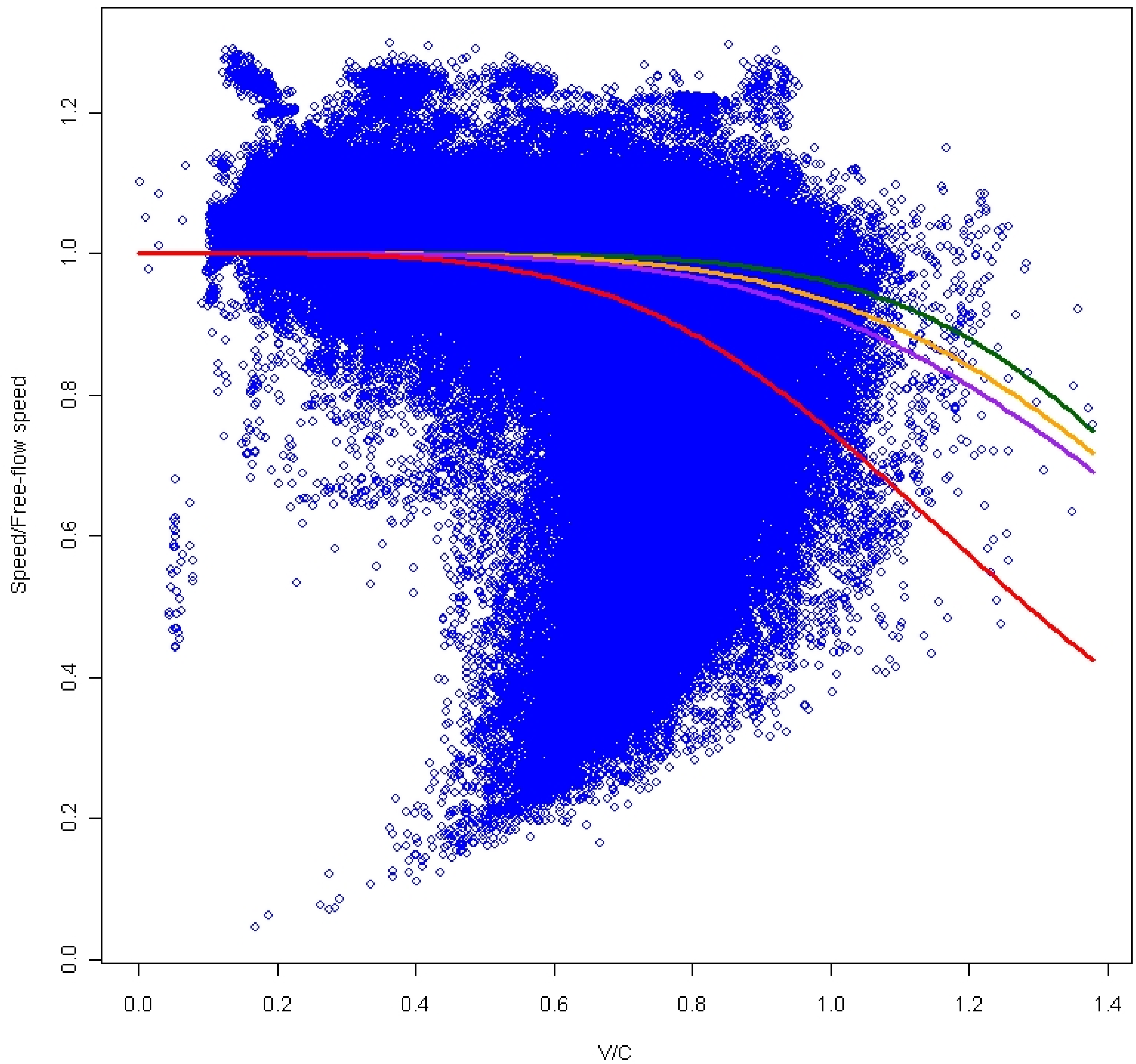

Figure 5-2. VDF curves vs. observed data, urban area type

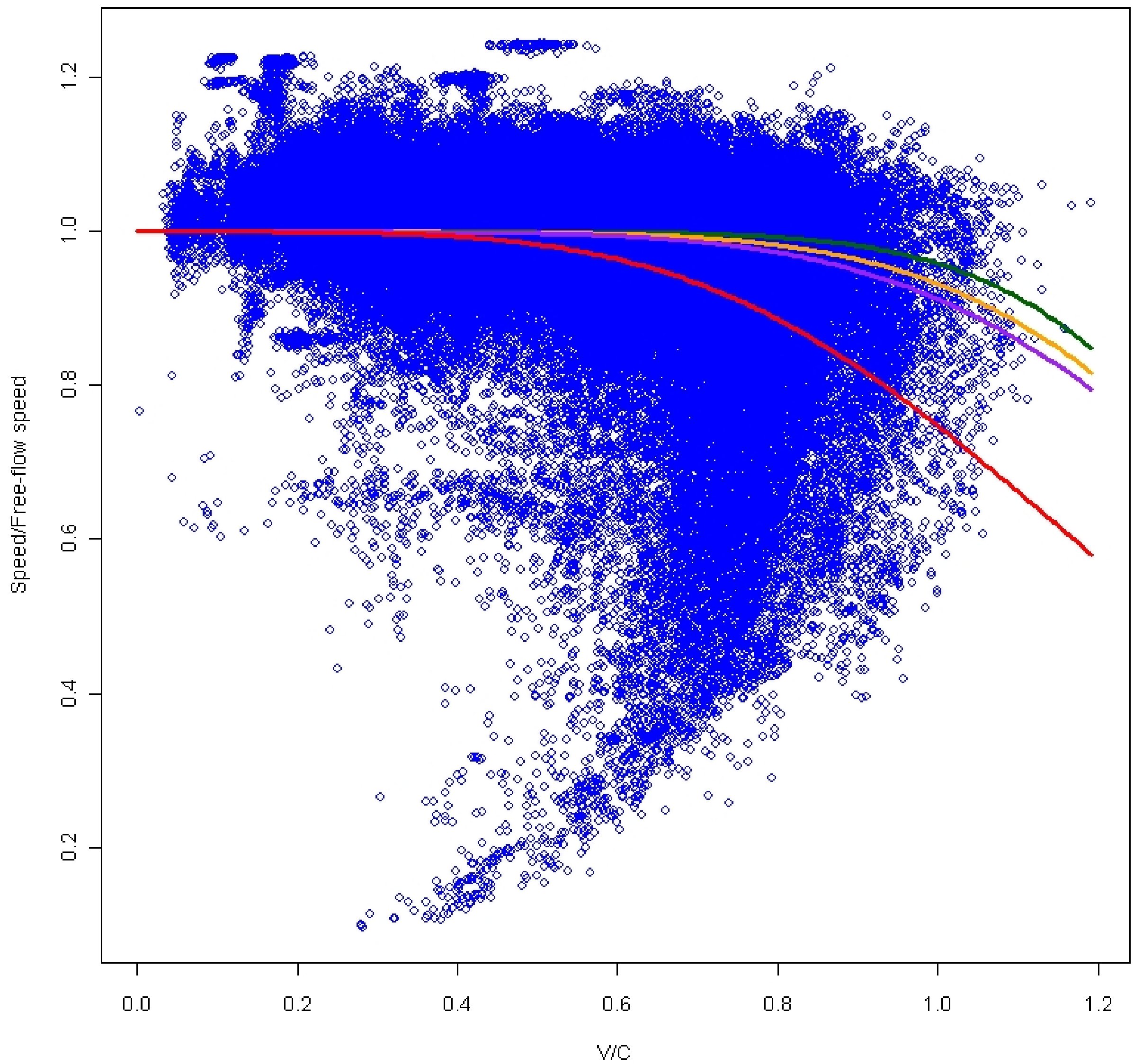

Figure 5-3. VDF curves vs. observed data, suburban area type

5.4 Preliminary Conclusions and Recommendations

The a factor from the curve-fitting estimates is significantly smaller than the SCAG value. It is also smaller than the recommended values in the 2000 Highway Capacity Manual. This is because the observed speeds at capacity are nearly equal to the free-flow speeds. The value of a is determined by the following equation:

$$a = \frac{S_{CAP}}{S_{FF}} - 1$$

where S_{CAP} is the speed when flow is at capacity. A visual inspection of the plots shows that the average speed at capacity is about 90% - 95% of the free-flow speed, giving a value for a of about 0.05 – 0.10. The SCAG BPR curve predicts an average speed at capacity of about 46% of the free-flow speed. The estimated values for *b* are significantly higher than the SCAG value, although they are within the range of recommended values in the 2000 Highway Capacity Manual.

The estimated values for *a* and *b* are highly influenced by observations in the V/C range from 0.2 – 0.8. It was not possible to obtain stable V/C estimates using only data for V/C > 0.8. Further adjustment of these curves will be based on review of results of validation runs from the SCAG model. We anticipate that the values for *a* may need be adjusted higher to reflect incipient breakdown as demand approaches capacity. The required adjustments to *b* will need to strike a balance between providing a sufficiently sharp dropoff in speeds for V/C > 1 and yet maintaining stability in the feedback process in the model.

The following table shows for the estimated curves with the steeper drop (higher *b* value), the estimated speed at capacity as a percentage of free-flow speed and the V/C ratios where the estimated curves "cross-over" (i.e., become lower than) the SCAG BPR curve.

Area type	**Parameter value**		**Speed/ffs at capacity**	**Crossover V/C**
	a	*b*		
Urban business dist.	0.0813	5.9122	92%	2.1
Urban	0.0982	4.7046	91%	2.7
Suburban	0.0958	5.6221	91%	1.7

Table 5-5. Comparative speeds at capacity and crossover v/c values for estimated VDFs

The observed 95th and 99th percentile speeds provide some guidance on likely values for free-flow speeds. For all area types the 95th percentile speeds are in the neighborhood of 70 – 75 mph, and the 99th percentile observed speeds are in the neighborhood of 75 mph. It would therefore appear reasonable to use 70 mph for free-flow speed for the Urban Business District, Urban, and Suburban area types, and 75mph for the Rural and Mountain area types.

The observed 99th percentile flows indicate that the capacity per lane-hour for the Urban Business District, Urban, and Suburban area types is close to 2,000 per lane-hour. Adjustment for trucks would likely increase this number to close to 2,100 per lane-hour. Our preliminary results therefore do not argue strongly for changing the value currently used by SCAG for freeway capacity.

6 Truck Speed Analysis

6.1 Introduction

Under Task 8 of the subject study, an investigation was to be conducted to ensure that the truck (i.e., heavy truck) speed post processor was compatible and consistent with the speeds produced by the new Volume Delay Functions (VDFs) being developed in the study.

Under individual work elements being completed by the June 30 end of SCAG's FY 2008, scheduling and resource constraints dictated the development of a preliminary conceptual approach, rather than an exhaustive quantitative analysis. However, a rich and robust source of actual heavy truck speeds has been identified that we recommend be used to validate truck speed predicted by SCAG's model post-processor. This chapter summarizes our investigation and describes an analytical framework that can be used to assess truck speed compatibility beyond the term of this contract.

6.2 Background

Truck Speed Processor

It is widely recognized that heavy-duty vehicles (e.g., trucks and buses) generally operate at somewhat lower average roadway speeds than the rest of the on-road vehicle fleet. As the linkages between transportation and air quality planning models have become better understood, some Metropolitan Planning Organizations (MPOs) have begun to develop explicit techniques that address these known speed differences. SCAG currently uses a simple post-processing technique to adjust model output speeds for heavy-duty trucks as described by the following equation:

$$\text{Heavy Duty Truck Speed} = 0.31 + (0.9657 \times \text{Average Freeway Speed}) \qquad (4\text{–}1)$$

Potential Validation Sources

Within the last decade, several studies or data sources have materialized that contain one-time or on-going measurements of heavy-duty vehicle speeds in Southern California.

First, the California Air Resources Board (CARB) sponsored two studies1,2 led by Battelle and Jack Faucett Associates in the late 1990s under which heavy-duty trucks were equipped with GPS-based instrumentation packages from which millions of second-by-second roadway position (latitude and longitude) and speed data were collected.[1, 1]

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[1] "Heavy-Duty Vehicle Truck Activity Data," prepared by Battelle for Planning and Technical Support Division, California Air Resources Board, March 31, 1999.

Under these studies, nearly 150 different heavy-duty vehicles ranging from urban delivery trucks to long-haul freight trucks were instrumented with the GPS systems and position and speed measurements were collected for up to a week per vehicle as they were operated under their normal usage patterns. Although these were statewide studies, much of the driving occurred within SCAG's jurisdictional boundaries in the South Coast Basin and adjoining inland desert areas. Because these datasets contain real-time second-by-second location and speed measurements, they offer a robust representation of actual, time-of-day-specific roadway speeds of heavy trucks.

Second, the Performance Monitoring System (PeMS) being developed and expanded in urban areas in California through funding from the California Department of Transportation (Caltrans) also offers a wealth of potential heavy-truck speed measurements along corridors where PeMS detectors have been deployed. (The magnetic loop-detector-based technology used in PeMS does not directly measure vehicle speeds; however, a complex package of post-processing techniques has been developed to infer speeds from measurements of pulse counts and durations.) Based on a cursory review of the capabilities of PeMS, there are questions about its ability to accurately resolve speeds of heavy trucks. The speed inferring post-processing techniques have largely focused on more uniformly sized light-duty vehicles. Since heavy trucks (especially those pulling one or more trailers) vary more significantly in size or "footprint," the speed post-processing techniques that are calibrated more toward light-duty vehicles tend to break down when used to estimate heavy truck speeds only.

In addition, although PeMS monitors are operated continuously (and can be used to provide data over integrated average time slices), they represent only single-point spatial measurements. Thus, an average speed over the extent of a roadway section corresponding to a modeling link must somehow be extrapolated from, or assumed to be represented by, a single PeMS loop detector. This becomes more problematic along corridors where dense networks of loop detectors do not exist or speed/flow varies more dramatically in space (e.g., arterial roadways).

For these reasons, our initial conceptual analysis has focused on the CARB heavy-truck speed datasets rather than the PeMS data.

Condition of Data

It should also be clearly noted that this task was scoped out under the understanding that a good portion of the raw CARB GPS-based measurements had been "map-matched" to a GIS layer of the actual California roadway system. (Map-matching refers to the process of snapping or matching each real-time position and speed measurement of a vehicle during a trip to a geospatial database representing the roadway system, usually within a GIS-based system.) GPS-based position measurements, especially before the U.S. military relaxed selective availability constraints (which significantly limited civilian GPS accuracy), often do not perfectly align with the roadway system.

[1] M. Fischer, "Heavy-Duty Truck Population, Activity and Usage Factors," prepared by Jack Faucett Associates for California Air Resources Board, July 1998.

The accuracy of the geo-coded roadway system also affects how well GPS data can be matched to it.

Battelle's report to CARB included a discussion that suggested that a portion of the data collected under that study had been mapped to a GIS-based roadway system. If this were the case, a fairly modest amount of effort would have been required to translate that GIS layer to one based on SCAG's current modeling link network. Unfortunately, Sierra learned from contacts with both current and former CARB staff3,4 involved with that study that a very limited amount of map-matching was actually performed and delivered to CARB and the data that were matched were of highly questionable quality.[1,2] Although the Faucett data were not map-matched under the original study, Sierra believed that CARB had performed map matching in-house following the study. Conversations with the aforementioned contacts indicated that this effort was never completed and that no partial data were available.

As a result, Sierra was forced to work with the "raw" databases collected under the Battelle and Faucett studies (which we had obtained under an earlier unrelated study for the U.S. Environmental Protection Agency).[3] These databases consisted simply of second-by-second measurements of GPS-based latitude and longitude coordinates and speeds (along with a date and time stamp). This approach used to analyze this data is described in the following section.

6.3 Conceptual Validation Analysis

Initial Data Processing

The Battelle and Faucett datasets as described above were first combined into a single, unified file structure using SAS (Statistical Analysis System) database analysis software licensed by Sierra. Basic statistics were tabulated from this combined database, which initially included all data collected statewide, not just in SCAG's planning area. The combined database contained some 12,000 individual trips from roughly 150 different heavy trucks and encompassed nearly 13 million second-by-second position and speed measurements.

Next, a simple spatial filter was applied to the database to generate a Southern California subset of the statewide database. All records with latitude coordinates less than 34.9°N (which corresponds to the approximate position of the Tejon Pass Summit separating the San Joaquin and San Fernando Valleys) were filtered into a working database of over 7 million records representing travel within Southern California.

[1] Personal communication with Jeff Long, California Air Resources Board, June 4, 2008.

[2] Personal communication with Mark Carlock, St Malo Solutions, June 11, 2008.

[3] T. Carlson, et al., "Development of Trip and Soak Activity Defaults for Passenger Cars and Trucks in MOVES," prepared for U.S. Environmental Protection Agency, Report No. SR2007-06-01, June 29, 2007.

Separate files for individual vehicles instrumented during the studies were generated from the working "Southern California" database. A total of 83 separate vehicle files were created and exported into both ASCII text and dBase (DBF) file formats.

Selected Sample Map-Matching

Files for two of the vehicles (one each from the Battelle and Faucett studies) were then further processed to map-match selected trip records for each vehicle to a GIS layer of SCAG's current TRANSCAD-based 2008 base year modeling network (provided to Sierra in November 2007 under a separate study).

Figure 6-1 contains a plotted overlay of the trip data for these two vehicles on top of the SCAG 2008 base year network. The Battelle (B) vehicle trips are depicted with various shades of pink; the Faucett (F) vehicle trips are plotted in blue shades. (Each change in shading marks a different trip.) As shown in Figure 1, many of the B trips occurred in the northern and eastern portions of the basin. The F trips largely occurred in central and southern Los Angeles County and in Orange County. Travel occurred on both freeways and arterial roads.

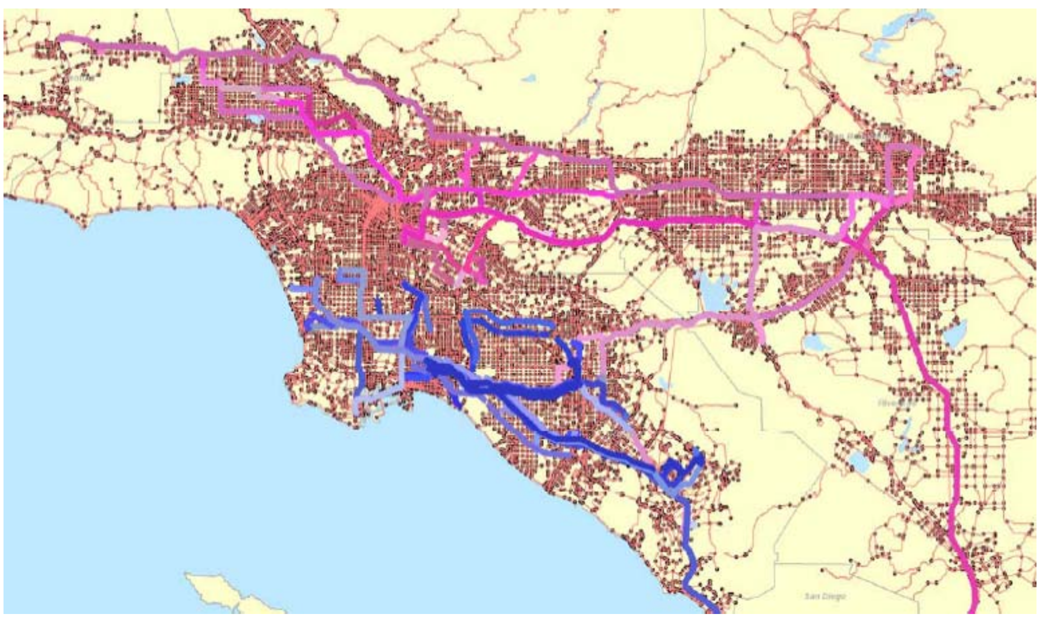


Figure 6-1. Overlay of South Coast basin truck trips for two sample vehicles

From this large-scale perspective, the GPS-based trip data appear to nicely align with the underlying roadway system. Figure 6-2 paints a more complicated picture. It shows a zoomed in area of less than one square mile in Compton east of I-110. The blue shaded cross "+" symbols mark each second-by-second position record as one of the sample vehicles traveled northbound on Central Ave, turned left onto Rosecrans Ave., and pulled into a business near the intersection of Central and Rosecrans. (Google Earth® revealed a McDonald's restaurant at that location.) The gap and slightly darker shaded set of parallel symbols indicate a new trip that began at this location and headed back southward on Central Ave.

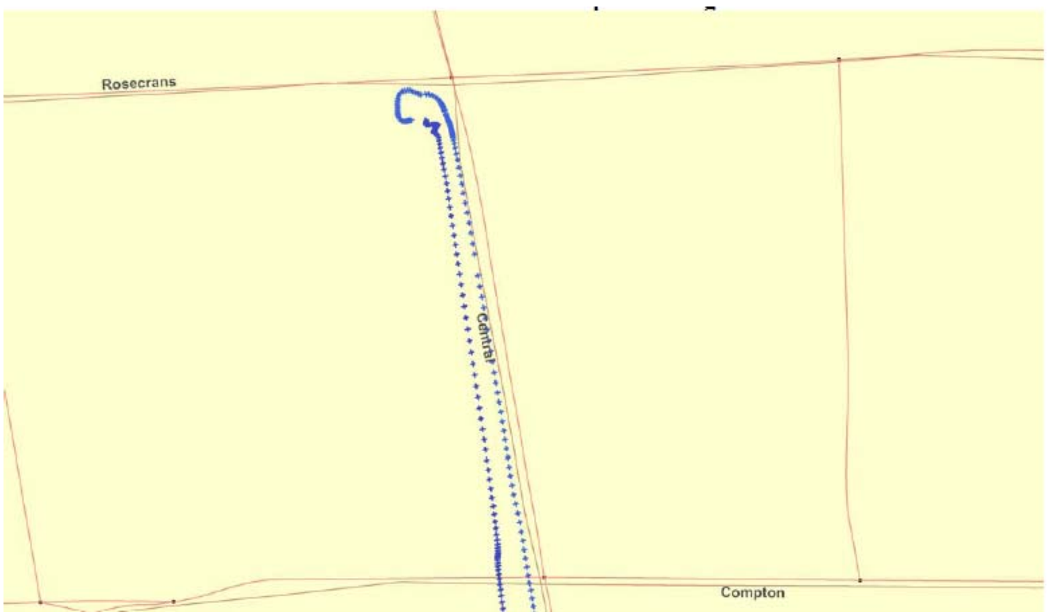


Figure 6-2. Visual illustration of map matching

Figure 6-2 shows, a spatial offset (roughly 50 feet) exists between the actual roadway and the plotted position data. (This offset occurs as both a westward and southward shift of the GPS data relative to the roadway layer.) This offset illustrates the difficulty and central mathematical problem in map-matching. Although the human eye and brain can identify where the vehicle was traveling, complex programming (and spatially accurate roadway data) is required to process large volumes of these data and successfully match or "snap" the GPS-based position data to the roadway system. Additional processing within a GIS system must then be performed to calculate and compare link average speed to that predicted by the travel model for the specific daily period (e.g., AM peak) when the travel occurred.

A small non-random sample of GPS trip data were map-matched to the SCAG 2008 base year modeling network in this manner using visual examination and data marking with Sierra's ArcGIS system. The limited sample was drawn only for illustrative purposes; in no way is it sufficient or representative to perform a statistical comparison to link speeds predicted by a travel model.

Table 6-1 summarizes the results. It shows travel times and average link speeds for some 16 directional network links in the El Segundo area from an out-and-back traverse of an arterial corridor collected around 8 PM on a Wednesday evening from the Faucett study. The measured average link speeds are highlighted in green. Street names, direction of travel, and cross streets are also listed.

Merging with Network Link Data

The final step in this conceptual analysis consisted of performing lookups of time-of-day-specific loaded network model outputs (using the 2008 base year outputs) of the network links in the selected sample.

Trip	Time of Day		Time (min)	Dist. (mi)	Speed (mph)	Street Name	Dir	Cross Streets	
	Start	End						Start	End
91	19:49:47	19:50:49	1.033	0.177	10.3	Main St	N	El Segundo Blvd	W Grand Ave
93	20:23:24	20:24:20	0.933	0.177	11.4	Main St	S	W Grand Ave	El Segundo Blvd
91	19:46:18	19:49:47	3.483	1.147	19.8	El Segundo Blvd	W	Sepulveda Blvd	Main St
93	20:24:20	20:27:08	2.800	1.147	24.6	El Segundo Blvd	E	Main St	Sepulveda Blvd
91	19:44:38	19:46:18	1.667	0.295	10.6	El Segundo Blvd	W	Continental Blvd	Sepulveda Blvd
93	20:27:08	20:27:44	0.600	0.295	29.5	El Segundo Blvd	E	Sepulveda Blvd	Continental Blvd
91	19:44:19	19:44:38	0.317	0.196	37.1	El Segundo Blvd	W	Nash St	Continental Blvd
93	20:27:44	20:28:04	0.333	0.196	35.2	El Segundo Blvd	E	Continental Blvd	Nash St
91	19:44:07	19:44:19	0.200	0.122	36.5	El Segundo Blvd	W	Metro Green Line Access Rd	Nash St
93	20:28:04	20:28:22	0.300	0.122	24.3	El Segundo Blvd	E	Nash St	Metro Green Line Access Rd
91	19:43:56	19:44:07	0.183	0.123	40.1	El Segundo Blvd	W	Douglas St	Metro Green Line Access Rd
93	20:28:22	20:28:35	0.217	0.123	33.9	El Segundo Blvd	E	Metro Green Line Access Rd	Douglas St
91	19:43:23	19:43:56	0.550	0.272	29.6	El Segundo Blvd	W	Aviation Blvd	Douglas St
93	20:28:35	20:29:06	0.517	0.272	31.5	El Segundo Blvd	E	Douglas St	Aviation Blvd
91	19:42:32	19:43:23	0.850	0.314	22.1	El Segundo Blvd	W	I-405 Fwy SB onramp	Aviation Blvd
93	20:29:06	20:29:43	0.617	0.314	30.5	El Segundo Blvd	E	Aviation Blvd	I-405 Fwy SB onramp

Table 6-1. Sample of measured heavy truck network link speeds

Table 6-2 presents these data and compares the model-based link speeds to the corresponding measured speeds in the map-matched sample. Both PM peak (3-7 PM) and nighttime (7 PM to 6 AM) model outputs are shown since the sample traverse occurred around 8 PM in the evening, during the transition period from congested evening flows to lower nighttime levels. Using the simple truck post-processor shown earlier in Equation 4–1, congested model speeds were adjusted downward to reflect heavy truck speeds. This adjustment is highlighted in the yellow shaded columns in Table 6-2. (Equation 4–1 is SCAG's freeway truck speed post-processor. Sierra was not sure if a separate equation exists for arterials, so the freeway equation was used for this conceptual analysis.)

The measured truck speeds from a single traverse of these links from the map-matched sample shown earlier in Table 6-1 are listed in the rightmost column of Table 6-2 (again shaded in green). These results between model-adjusted and measured heavy trucks speeds are merely compared in Table 6-2 for illustrative purposes. In general, the measured speeds are in better agreement with the model-adjusted speeds for the PM peak than the nighttime period. This is not surprising since the time these links were driven (around 8 PM) is still close to the end of the PM peak period and traffic remains more elevated than during the middle of the nighttime period.

The map-matched sample presented in this conceptual analysis is obviously too limited to draw any quantitative or qualitative conclusions about their differences. However, this conceptual analysis shows that statistical comparisons can be performed once a broader sample of map-matched truck speed data can be processed and linked to the corresponding link outputs from SCAG's model.

ANode	BNode	Dist. (mi)	Model Times (min)		Model Speeds (mph)		Truck Speeds (mph)		Measured Spd (mph)
			PM Peak	Night	PM Peak	Night	PM Peak	Night	
88556	88935	0.177	0.552	0.471	19.3	22.6	18.9	22.1	10.3
88935	88556	0.177	0.536	0.473	19.9	22.5	19.5	22.0	11.4
88938	88556	1.147	2.812	2.509	24.5	27.4	23.9	26.8	19.8
88556	88938	1.147	3.157	2.528	21.8	27.2	21.4	26.6	24.6
88504	88938	0.295	0.678	0.550	26.1	32.2	25.5	31.4	10.6
88938	88504	0.295	0.662	0.549	26.7	32.2	26.1	31.4	29.5
89945	88504	0.196	0.439	0.387	26.8	30.3	26.2	29.6	37.1
88504	89945	0.196	0.476	0.388	24.7	30.3	24.1	29.5	35.2
124756	89945	0.122	0.264	0.241	27.7	30.2	27.1	29.5	36.5
89945	124756	0.122	0.344	0.244	21.3	29.9	20.8	29.2	24.3
89944	124756	0.123	0.261	0.242	28.1	30.4	27.5	29.6	40.1
124756	89944	0.123	0.373	0.247	19.7	29.8	19.3	29.1	33.9
89946	89944	0.272	0.620	0.536	26.3	30.4	25.7	29.7	29.6
89944	89946	0.272	0.691	0.534	23.6	30.5	23.1	29.8	31.5
77417	89946	0.314	0.811	0.600	23.2	31.4	22.7	30.6	22.1
89946	77417	0.314	1.146	0.600	16.4	31.4	16.2	30.6	30.5

Table 6-2. Comparison to 2008 base year PM and night loaded network link outputs

The data presented in this conceptual analysis represent an extremely small fraction of the measured truck speeds contained in these CARB datasets. Using the simple filter to identify Southern California trips described earlier, a total of over 5,000 truck trips were culled from the statewide datasets. Assuming each truck trip had an average duration of 20 minutes (a reasonable estimate for heavy trucks) and each trip encompassed 20 directional network links, a total of 2,000,000 average link speed measurements could be "mined" from these datasets and compared to model-based link speeds by time of day. In many instances, especially on freeways, multiple measurements from traverses of the same link are likely to be available. This would aid in developing an integrated average of truck speeds over a multi-hour modeling period (e.g., the PM peak) and enable a robust comparison to model-predicted speeds.

6.4 Recommendations for Further Study

The CARB GPS-instrumented heavy truck datasets from the Battelle and Faucett studies represent a very rich and robust data source for validating SCAG's truck post-processor adjustments and ensuring consistency with all-vehicle Volume Delay Functions developed under other tasks within this study. Although resources and schedule were constrained under this contract (and affected by that fact that these data had not been map-matched as previously believed), the conceptual analysis performed under this study clearly illustrates the value of further spatially mining these CARB datasets and their potential for broad validation of SCAG's truck speed modeling techniques.

As a result, our study team strongly recommends that SCAG consider funding a follow-on effort as resources are available to extract and compare actual map-matched truck speeds to model estimates at both the corridor and individual link level.

Performing the necessary map-matching exercises for each of roughly 5,000 instrumented truck trips (encompassing an estimated 2,000,000 link traverses) will likely require a significant level of effort. We are not currently in a position to provide SCAG with a credible estimate of the resources required to conduct the analysis. However, it could be significantly minimized with:

1. Availability of Linear Reference System (LRS) attributes for each modeling link in SCAGs network; or

2. A carefully drawn random sample of a workable subset of the trips encompassed in these datasets.

7 Model Validation

7.1 Introduction

SCAG reviewed the initial VDF estimation results and requested additional analyses from Dowling:

- Investigate whether speed-flow relationships on freeways differ significantly by number of lanes

- Investigate whether speed-flow relationships on HOV lanes are significantly different from those on general-purpose lanes

The analyses, described in section 7.2, resulted in a different set of freeway VDF recommendations. These were implemented by SCAG in their regional model. The results of the model runs showed a significant over-assignment to freeways and under-assignment to arterials. After further discussions with SCAG we jointly developed a further set of VDF functions for arterials and freeways; the results are discussed in section 7.3.

7.2 Freeway VDF Estimates by Facility Type and Number of Lanes

Data Sources

Data for VDF estimation were developed from 2008 PeMS hourly speed-volume data for the SCAG region. The following were the steps used to produce the freeway VDF estimation data set:

1. Selectively download PeMS hourly speed-volume data for the SCAG region.

2. Filter the data for quality: i.e., an adequate percentage of observed (vs. imputed) values.

3. Aggregate the data according to SCAG time periods, resulting in one observation per time period. The following time period definitions were used: AM peak (0600 – 0900), PM peak (1500 – 1900), midday (0900 – 1500), and night (1900 – 0600).

4. Merge the data with SCAG network data to assign the network data – area type, county, free-flow speed, and capacity – to each PeMS station. For the PeMS mainline stations, we used the network data that were already attached from previous work. For the PeMS HOV stations, there was no entry in the pems_id field in the SCAG network data. We first tried a GIS matching of PeMS HOV stations to the SCAG network line file, but this proved infeasible. We then matched each PeMS HOV station to an adjacent PeMS mainline station based on route, direction of travel, and postmile; the network characteristics of the

corresponding PeMS mainline station were then attached to the PeMS HOV station.

5. Check free-flow speeds and capacities in the merged data set and remove outliers. The resulting data set

We selected PeMS data using these criteria:

- PeMS stations within the SCAG region (Caltrans Districts 07, 08, and 12)
- Weekdays between 1 April 2008 and 31 October 2008. These date limits were selected to 1) provide the most recent available data, 2) minimize the chance of inclement weather confounding the observations, and 3) ensure good daylight conditions during both peak periods.
- Data points with a minimum of 75% observed. PeMS always imputes data to fill in missing data points. The 75% threshold provides a realistic balance between data quality and quantity.

Table 7-1 shows a tabulation of the number of PeMS mainline stations with data that met these criteria by county, number of lanes, and area type; Table 7-2 shows the same information for PeMS HOV stations.

Hourly PeMS data were aggregated into the four SCAG time periods. Data for an individual time period for a given day were not considered complete unless each PeMS hourly observation for that time period met the 75% observed threshold. Time period data were further filtered to eliminate the following outliers:

- Observations where the volume is greater than 125% of capacity.
- Observations where the observed speed is greater than 150% of the free-flow speed.

The number of time period observations by area type and county are shown in Table 7-3 for mainline locations and Table 7-4 for HOV locations.

County	No. lanes	Area type							Total
		Core	CBD	Urban bus. dist	Urban	Sub-urban	Rural	Mount-ain	
Imperial	Subtotal	0	0	0	0	0	0	0	0
Los Angeles	2	0	0	0	4	1	0	0	5
	3	0	0	18	55	17	0	0	90
	4	1	1	123	264	100	6	0	495
	5	0	3	50	68	16	0	0	137
	6	0	0	8	8	0	0	0	16
	Subtotal	1	4	199	399	134	6	0	743
Orange	2	0	0	2	4	18	4	0	28
	3	0	3	17	20	13	3	0	56
	4	0	1	49	103	51	0	0	204
	5	0	2	27	21	13	1	0	64
	6	0	0	3	1	4	0	0	8
	7	0	0	0	1	0	0	0	1
	Subtotal	0	6	98	150	99	8	0	361
Riverside	3	0	0	5	9	9	0	0	23
	4	0	0	0	7	13	0	0	20
	Subtotal	0	0	5	16	22	0	0	43
San Bernardino	3	0	0	2	2	13	0	0	17
	4	0	0	14	30	19	0	0	63
	Subtotal	0	0	16	32	32	0	0	80
Ventura	2	0	0	0	0	3	0	0	3
	3	0	0	1	11	11	0	0	23
	4	0	0	0	2	3	0	0	5
	Subtotal	0	0	1	13	17	0	0	31
All counties	2	0	0	2	8	22	4	0	36
	3	0	3	43	97	63	3	0	209
	4	1	2	186	406	186	6	0	787
	5	0	5	77	89	29	1	0	201
	6	0	0	11	9	4	0	0	24
	7	0	0	0	1	0	0	0	1
	Total	1	10	319	610	304	14	0	1,258

Table 7-1. Number of PeMS mainline stations by county, number of lanes, and area type

County	No. lanes	Area type							Total
		Core	CBD	Urban bus. dist	Urban	Sub-urban	Rural	Mount -ain	
Imperial	Subtotal	0	0	0	0	0	0	0	0
Los Angeles	1	0	2	107	215	71	4	0	399
	2	0	1	0	10	0	0	0	11
	Subtotal	0	3	107	225	71	4	0	410
Orange	1	0	6	86	120	35	0	0	247
	2	0	0	6	4	13	1	0	24
	Subtotal	0	6	92	124	48	1	0	271
Riverside	1	0	0	0	13	13	0	0	26
San Bernardino	1	0	0	5	18	21	0	0	44
Ventura	1	0	0	0	0	1	0	0	1
All counties	1	0	8	198	366	141	4	0	717
	2	0	1	6	14	13	1	0	35
	Total	0	9	204	380	154	5	0	752

Table 7-2. Number of PeMS HOV stations by county, number of lanes, and area type

County	No. lanes	Area type							Total
		Core	CBD	Urban bus. dist	Urban	Sub-urban	Rural	Mount-ain	
Imperial	Subtotal	0	0	0	0	0	0	0	0
Los Angeles	2	0	0	0	1,654	556	0	0	2,210
	3	0	0	7,293	22,766	7,393	0	0	37,452
	4	471	334	50,879	118,033	44,268	2,225	0	216,210
	5	0	1,259	19,034	28,374	5,246	0	0	53,913
	6	0	0	3,425	2,935	0	0	0	6,360
	Subtotal	471	1,593	80,631	173,762	57,463	2,225	0	316,145
Orange	2	0	0	1,138	1,860	8,042	1,471	0	12,511
	3	0	1,679	7,133	8,232	5,030	1,304	0	23,378
	4	0	573	22,770	44,503	24,453	0	0	92,299
	5	0	257	13,687	9,583	5,805	544	0	29,876
	6	0	0	1,571	259	1,933	0	0	3,763
	7	0	0	0	483	0	0	0	483
	Subtotal	0	2,509	46,299	64,920	45,263	3,319	0	162,310
Riverside	3	0	0	1,637	3,943	4,363	0	0	9,943
	4	0	0	0	3,226	6,444	0	0	9,670
	Subtotal	0	0	1,637	7,169	10,807	0	0	19,613
San Bernardino	3	0	0	615	354	5,760	0	0	6,729
	4	0	0	6,173	15,354	9,095	0	0	30,622
	Subtotal	0	0	6,788	15,708	14,855	0	0	37,351
Ventura	2	0	0	0	0	1,244	0	0	1,244
	3	0	0	303	4,588	3,829	0	0	8,720
	4	0	0	0	703	1,620	0	0	2,323
	Subtotal	0	0	303	5,291	6,693	0	0	12,287
All counties	2	0	0	1,138	3,514	9,842	1,471	0	15,965
	3	0	1,679	16,981	39,883	26,375	1,304	0	86,222
	4	471	907	79,822	181,819	85,880	2,225	0	351,124
	5	0	1,516	32,721	37,957	11,051	544	0	83,789
	6	0	0	4,996	3,194	1,933	0	0	10,123
	7	0	0	0	483	0	0	0	483
	Total	471	4,102	135,658	266,850	135,081	5,544	0	547,706

Table 7-3. Number of PeMS mainline time period data points by county, number of lanes, and area type

County	No. lanes	Area type							Total
		Core	CBD	Urban bus. dist	Urban	Sub-urban	Rural	Mount-ain	
Imperial	Subtotal	0	0	0	0	0	0	0	0
Los Angeles	1	0	512	44,662	92,904	29,176	1,143	0	168,397
	2	0	531	0	4,587	0	0	0	5,118
	Subtotal	0	1,043	44,662	97,491	29,176	1,143	0	173,515
Orange	1	0	1,198	40,302	52,949	14,623	0	0	109,072
	2	0	0	2,225	1,991	6,541	544	0	11,301
	Subtotal	0	1,198	42,527	54,940	21,164	544	0	120,373
Riverside	1	0	0	0	5,446	6,321	0	0	11,767
San Bernardino	1	0	0	2,119	9,284	9,631	0	0	21,034
Ventura	1	0	0	0	0	324	0	0	324
All counties	1	0	1,710	87,083	160,583	60,075	1,143	0	310,594
	2	0	531	2,225	6,578	6,541	544	0	16,419
	Total	0	2,241	89,308	167,161	66,616	1,687	0	327,013

Table 7-4. Number of PeMS mainline time period data points by county, number of lanes, and area type

For purposes of analysis we defined several sets of categories of numbers of lanes as follows:

- Mainline
  - 2 lanes
  - 3 lanes
  - 4 lanes
  - 5 or more lanes
- HOV
  - 1 lane
  - 2 lanes

Data Tabulations

Table 7-5 and Table 7-6 show observed speeds and volume quantiles respectively for PeMS stations in the sample by facility type, area type, and number of lanes. Because the number of observations for the Core, CBD, Rural, and Mountain area types are rather small, the standard errors of these quantile estimates are comparatively larger than those for the Urban business district, Urban, and Suburban area types.In general, it appears that speeds are lower and lane volumes are higher for facilities with more lanes.

Because of lack of sufficient number of stations or observations for the Core, CBD, Rural, and Mountain area types, we proceeded to estimate VDFs for Urban business district, Urban, and Suburban area types only.

Facility type	Area type	No. lanes	Percentile					
			50	75	85	90	95	99
Mainline	CBD	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
		3	65.8	67.0	67.4	67.9	69.0	70.9
		4	52.8	67.3	71.5	73.1	74.0	75.0
		5+	61.6	67.4	70.4	71.7	73.6	76.1
	Urban bus dist	2	50.0	53.7	55.0	65.3	67.8	69.7
		3	65.1	67.9	69.9	72.7	75.4	77.3
		4	63.7	67.5	68.9	69.7	72.0	77.7
		5+	65.1	69.3	70.7	71.5	72.9	77.2
	Urban	2	67.0	76.2	78.0	78.6	79.1	79.3
		3	64.9	68.0	70.1	72.3	75.3	77.5
		4	63.7	67.4	68.7	69.5	71.1	76.6
		5+	65.0	69.2	70.6	71.5	73.0	80.6
	Suburban	2	68.0	74.5	77.0	77.4	77.9	80.8
		3	65.1	67.6	68.9	70.1	76.4	78.9
		4	65.0	67.9	69.0	69.8	71.4	77.1
		5+	64.5	69.1	70.9	71.9	73.1	74.9
	Rural	2	76.4	76.9	77.4	77.7	78.2	78.4
		3	69.2	74.5	75.4	76.1	77.2	77.7
		4	62.2	66.3	69.2	70.4	71.3	73.0
		5+	68.3	69.8	70.4	70.7	71.2	72.3
HOV	CBD	1	62.4	65.5	69.0	71.1	73.2	74.9
		2	62.7	64.2	64.8	65.1	65.6	66.2
	Urban bus dist	1	62.8	65.0	66.5	68.8	74.6	75.0
		2	60.7	63.1	63.9	64.3	65.1	67.2
	Urban	1	62.3	64.5	65.6	67.0	72.1	75.0
		2	61.6	64.0	65.1	66.1	68.8	71.4
	Suburban	1	62.8	64.7	65.6	66.7	70.1	75.0
		2	62.8	66.4	69.3	70.6	72.8	74.8
	Rural	1	64.5	68.1	70.9	72.0	73.7	74.4
		2	65.1	65.9	66.2	66.5	66.8	67.2

n.d. = no data

Table 7-5. Observed speed quantiles by facility type, area type, and number of lanes

Facility type	Area type	No. lanes	Percentile					
			50	75	85	90	95	99
Mainline	CBD	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
		3	909	1,153	1,263	1,311	1,386	1,465
		4	1,103	1,261	1,349	1,407	1,456	1,509
		5+	1,310	1,531	1,597	1,650	1,691	1,788
	Urban bus dist	2	256	614	694	711	730	752
		3	1,123	1,456	1,548	1,596	1,656	1,878
		4	1,327	1,532	1,634	1,708	1,800	1,991
		5+	1,412	1,634	1,723	1,784	1,867	2,006
	Urban	2	546	767	1,066	1,223	1,490	1,584
		3	1,197	1,541	1,659	1,728	1,813	1,967
		4	1,357	1,546	1,631	1,694	1,793	1,985
		5+	1,306	1,511	1,603	1,658	1,752	1,898
	Suburban	2	370	842	999	1,090	1,347	1,727
		3	1,023	1,361	1,502	1,593	1,713	1,864
		4	1,166	1,440	1,546	1,611	1,697	1,882
		5+	1,280	1,437	1,542	1,596	1,687	1,879
	Rural	2	251	315	504	571	604	642
		3	368	700	808	831	897	1,015
		4	624	1,154	1,267	1,313	1,385	1,460
		5+	1,435	1,727	1,839	1,861	1,887	1,916
HOV	CBD	1	649	1,347	1,635	1,701	2,124	2,212
		2	585	965	1,224	1,253	1,308	1,341
	Urban bus dist	1	565	926	1,130	1,296	1,458	1,921
		2	702	986	1,053	1,137	1,395	1,701
	Urban	1	613	1,013	1,240	1,380	1,556	2,047
		2	667	972	1,182	1,250	1,351	1,452
	Suburban	1	594	979	1,212	1,336	1,470	1,917
		2	399	841	1,051	1,221	1,442	1,697
	Rural	1	456	682	1,027	1,057	1,087	1,130
		2	656	735	765	782	820	900

n.d. = no data

Table 7-6. Observed volume/lane-hr quantiles by facility type, area type, and number of lanes

VDF Estimation

Exploratory Analysis

As an initial step we estimated a simple log-log regression model to test whether the number of lanes significantly affects the ratio of observed to free-flow speeds. The following model was estimated for the free-flow regime (observed to free-flow speed in the range 0.7 – 1.2 and maximum V/C = 1.1; area types 3, 4, and 5):

$$\log\left(\frac{\text{observed speed}}{\text{free-flow speed}}\right) = \beta_0 + \beta_1 \log\left(V/C\right) + \beta_2 \log\left(\#\ \text{lanes}\right) + \beta_3 AT_3 + \beta_4 AT_4$$

where AT3 and AT4 are dummy variables denoting area types 3 and 4 respectively. The regression results are shown in Table 7-7.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.0820962	0.001055	-77.809	< 2e-16
log(V/C)	-0.0539602	0.000247	-218.784	< 2e-16
log(no. lanes)	0.0208620	0.000731	28.525	< 2e-16
area type 3	0.0070972	0.000381	18.642	< 2e-16
area type 4	0.0014797	0.000324	4.571	4.86e-06

Residual standard error: 0.08947 on 460128 degrees of freedom
Multiple R-squared: 0.09698, Adjusted R-squared: 0.09697
F-statistic: 1.235e+04 on 4 and 460128 DF, p-value: < 2.2e-16

Table 7-7. Exploratory regression results

What is most significant about this regression result is that the number of lanes is highly significant – even more so than the area type – in determining speed; if the number of lanes were not significant, its coefficient would not differ significantly from zero. Hence, these results suggest that the number of lanes affects the speed-flow relationship above and beyond how it affects V/C.

VDF Estimation

Several VDFs were estimated for each facility type, area type, and lane configuration. In order to avoid confounding the estimates, data points were selected for the free-flow regime. Data points were selected for several levels of minimum ratios of observed to free-flow speeds. VDFs were estimated for the following BPR model:

$$\frac{S}{S_{ff}} = \frac{1}{1 + aVC^b}$$

where

$$\begin{aligned} S_{ff} &= \text{free-flow speed} \\ S &= \text{observed speed} \\ VC &= \text{ volume/capacity} \\ a,b &= \text{ parameters to be estimated} \end{aligned}$$

The estimates were carried out using the non-linear least-squares estimation routine **`nls`** in R, an open-source data analysis package.[1]

[1] R Development Core Team (2009). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

We estimated an initial set of VDFs for mainline and HOV facilities by area type and number of lanes for several cutoff values of minimum speed/free-flow speed. These estimates are presented in Table 8 for mainline facilities and Table 9 for HOV facilities.

We estimated an initial set of VDFs for mainline and HOV facilities by area type and number of lanes for several cutoff values of minimum speed/free-flow speed. These estimates are presented in Table 7-8 for mainline facilities and Table 7-9 for HOV facilities.

Min speed/ff speed	Area type	No. lanes	Sample size	Parameter estimates		Std. errors		t-statistics		p*		Std err resid-uals
				a	b	a	B	a	b	a	b	
0.75	Urban bus dist	2	608	—	—	—	—	—	—	—	—	—
		3	13,780	0.17	6.85	0.01	0.37	14.56	18.66	0.00	0.00	0.09
		4	65,228	0.08	3.41	0.00	0.10	43.91	35.45	0.00	0.00	0.09
		5+	31,791	—	—	—	—	—	—	—	—	—
	Urban	2	2,829	0.58	7.79	0.38	2.51	1.53	3.10	0.13	0.00	0.10
		3	34,089	—	—	—	—	—	—	—	—	—
		4	154,773	0.10	3.50	0.00	0.05	80.65	68.97	0.00	0.00	0.08
		5+	34,860	0.13	5.15	0.00	0.15	32.50	34.85	0.00	0.00	0.09
	Sub-urban	2	8,932	0.38	6.69	0.11	0.97	3.32	6.89	0.00	0.00	0.12
		3	24,084	0.17	4.81	0.01	0.14	30.84	33.73	0.00	0.00	0.08
		4	77,884	0.11	4.30	0.00	0.10	40.89	44.95	0.00	0.00	0.08
		5+	11,275	0.16	6.73	0.01	0.31	19.88	21.42	0.00	0.00	0.09
0.80	Urban bus dist	2	417	—	—	—	—	—	—	—	—	—
		3	13,235	—	—	—	—	—	—	—	—	—
		4	62,496	0.05	3.82	0.00	0.15	30.60	25.77	0.00	0.00	0.08
		5+	30,540	0.06	8.09	0.00	0.39	23.96	20.83	0.00	0.00	0.08
	Urban	2	2,802	0.52	8.30	0.45	3.35	1.16	2.48	0.25	0.01	0.09
		3	32,899	—	—	—	—	—	—	—	—	—
		4	148,406	0.07	3.75	0.00	0.07	62.86	55.66	0.00	0.00	0.07
		5+	33,520	0.10	5.82	0.00	0.22	24.24	26.68	0.00	0.00	0.08
	Sub-urban	2	8,417	0.30	6.93	0.10	1.12	2.99	6.18	0.00	0.00	0.12
		3	23,545	0.15	5.15	0.01	0.17	27.01	30.10	0.00	0.00	0.07
		4	75,483	0.09	4.82	0.00	0.13	31.79	36.60	0.00	0.00	0.07
		5+	10,872	0.14	8.46	0.01	0.51	15.92	16.50	0.00	0.00	0.08

* p = probability that the true value of the parameter does **not** differ significantly from zero. Lower values indicate more significant parameter estimates. Zero values indicate p values less than 0.01 (highly significant).

Note: For all models, max speed/ff speed = 1.2, max V/C = 1.1. Blank entries denote models that did not converge or produced unreasonable values.

Table 7-8. BPR parameter estimates by area type and number of lanes, mainline facilities

Min speed/ff speed	Area type	No. lanes	Sample size	Parameter estimates		Std. errors		t-statistics		p*		Std err resid-uals
				a	b	a	B	A	b	a	b	
0.85	Urban bus dist	2	166	—	—	—	—	—	—	—	—	—
		3	12,641	—	—	—	—	—	—	—	—	—
		4	58,908	0.02	4.61	0.00	0.44	11.74	10.48	0.00	0.00	0.07
		5+	29,095	—	—	—	—	—	—	—	—	—
	Urban	2	2,749	0.47	10.07	0.78	6.68	0.60	1.51	0.55	0.13	0.09
		3	31,156	—	—	—	—	—	—	—	—	—
		4	139,317	0.05	4.53	0.00	0.12	38.20	36.70	0.00	0.00	0.07
		5+	31,672	—	—	—	—	—	—	—	—	—
	Sub-urban	2	8,115	0.13	6.98	0.08	2.13	1.69	3.27	0.09	0.00	0.11
		3	22,419	0.13	6.28	0.01	0.26	20.91	24.48	0.00	0.00	0.07
		4	71,976	—	—	—	—	—	—	—	—	—
		5+	10,280	—	—	—	—	—	—	—	—	—

* p = probability that the true value of the parameter does **not** differ significantly from zero. Lower values indicate more significant parameter estimates. Zero values indicate p values less than 0.01 (highly significant).

Note: For all models, max speed/ff speed = 1.2, max V/C = 1.1. Blank entries denote models that did not converge or produced unreasonable values.

Table 7-8 (cont). BPR parameter estimates by area type and number of lanes, mainline facilities

Min speed/ff speed	Area type	No. lanes	Sample size	Parameter estimates		Std. errors		t-statistics		p*		Std err resid-uals
				a	b	a	b	A	B	a	b	
0.75	Urban bus dist	1	76,587	0.14	1.30	0.00	0.02	65.67	67.08	0.00	0.00	0.08
		2	1,862	—	—	—	—	—	—	—	—	—
	Urban	1	138,508	0.11	0.76	0.00	0.01	117.57	85.87	0.00	0.00	0.08
		2	5,873	0.21	1.19	0.01	0.05	26.63	26.27	0.00	0.00	0.07
	Sub-urban	1	53,195	0.16	1.17	0.00	0.02	77.17	72.81	0.00	0.00	0.07
		2	6,091	0.11	1.00	0.01	0.06	17.02	15.55	0.00	0.00	0.09
0.80	Urban bus dist	1	73,971	0.10	1.21	0.00	0.02	53.25	53.37	0.00	0.00	0.07
		2	1,820	—	—	—	—	—	—	—	—	—
	Urban	1	131,050	0.08	0.70	0.00	0.01	97.83	69.51	0.00	0.00	0.07
		2	5,465	0.20	1.40	0.01	0.05	25.08	27.66	0.00	0.00	0.06
	Sub-urban	1	51,105	0.11	1.00	0.00	0.02	64.67	58.04	0.00	0.00	0.06
		2	5,874	0.10	1.23	0.01	0.09	14.85	14.30	0.00	0.00	0.08
0.85	Urban bus dist	1	69,839	0.06	1.16	0.00	0.03	35.27	35.35	0.00	0.00	0.07
		2	1,674	0.06	0.04	0.00	0.03	22.48	1.32	0.00	0.19	0.04
	Urban	1	122,119	0.05	0.61	0.00	0.01	70.49	47.05	0.00	0.00	0.06
		2	5,059	0.14	1.20	0.01	0.06	20.91	21.65	0.00	0.00	0.05
	Sub-urban	1	48,020	0.07	0.85	0.00	0.02	48.37	40.90	0.00	0.00	0.06
		2	5,497	0.09	1.83	0.01	0.19	9.46	9.69	0.00	0.00	0.07

* p = probability that the true value of the parameter does **not** differ significantly from zero. Lower values indicate more significant parameter estimates. Zero values indicate p values less than 0.01 (highly significant).

Note: For all models, max speed/ff speed = 1.2, max V/C = 1.1. Blank entries denote models that did not converge or produced unreasonable values.

Table 7-9. BPR parameter estimates by area type and number of lanes, HOV facilities

As shown in Table 7-8, a number of mainline facility models either failed to converge or produced unreasonable parameter estimates. For those models that could be estimated, the steepness of the curves appears to be greatest for 2-lane and 5+-lane facilities. Going from 2 lanes to 4 lanes, the steepness of the curves appears to decrease. The increase in steepness for 5+ lane facilities appears to be an artifact of greater congestion on the 5+ lane facilities (see the observed percentile speeds and volumes in Table 7-5 and Table 7-6).

For HOV facilities, the estimated steepness of the VDF curves is much shallower than that for mainline facilities. We believe that this is primarily an artifact of how the HOV lanes operate: most HOV operation appears to be at volumes less than 1,500 vehicles per lane-hr.

In order to help diagnose the results in Table 7-8 and Table 7-9 we plotted the ratio of speed/free-flow speed vs. V/C for several lane configurations. The results are shown in the following figures.

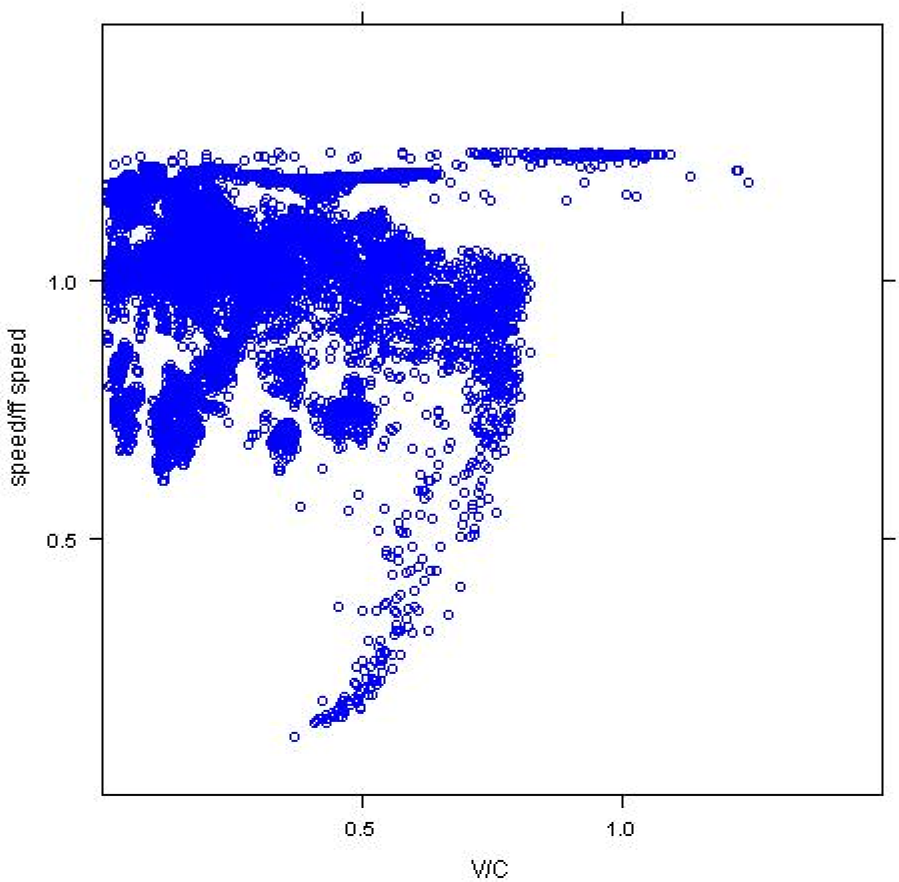


Figure 7-1. Speed/free-flow speed vs. v/c, general-purpose lanes, 2-lane facilities

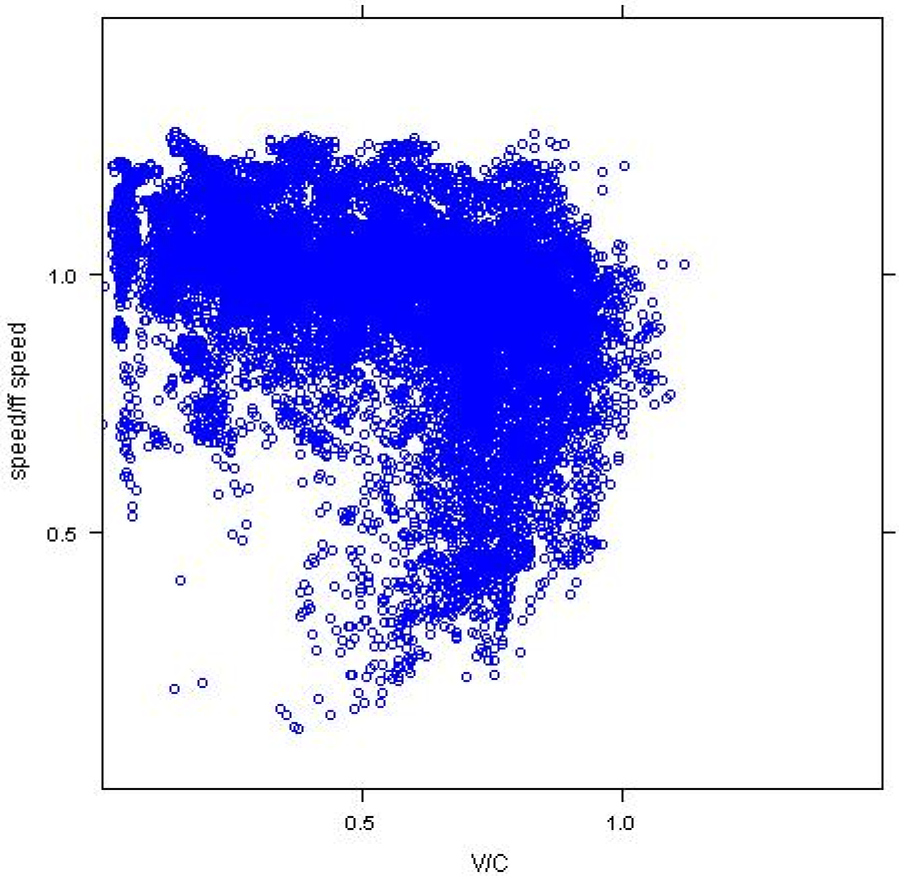


Figure 7-2. Speed/free-flow speed vs. v/c, general-purpose lanes, 3-lane facilities

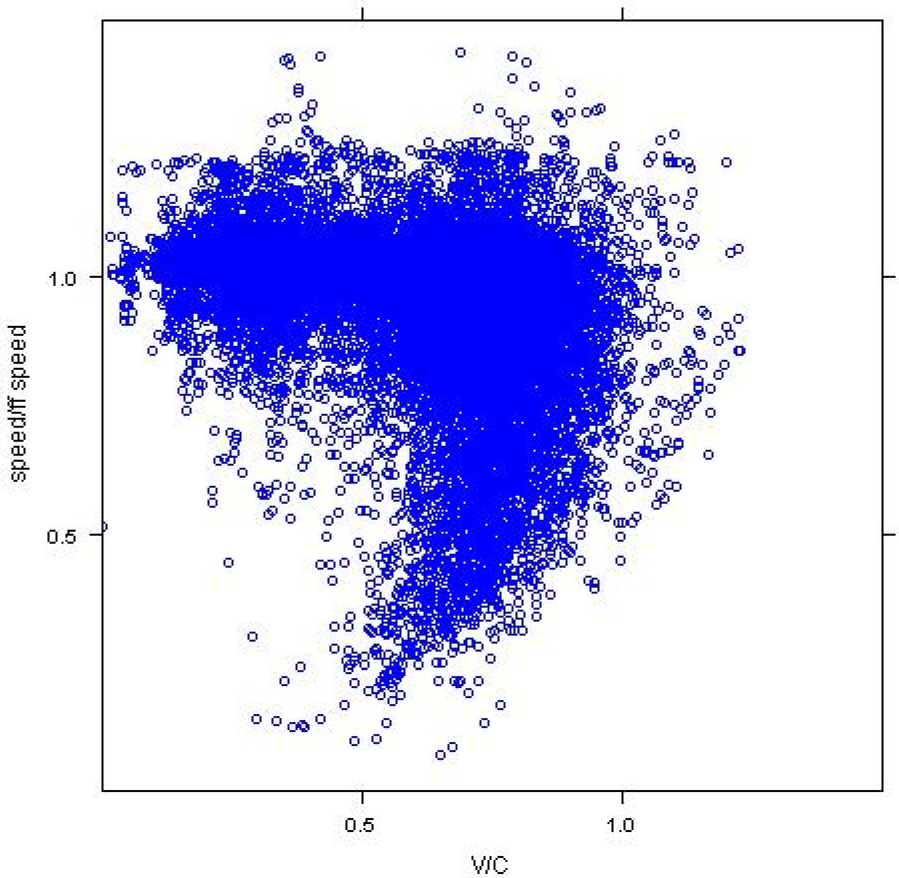


Figure 7-3. Speed/free-flow speed vs. v/c, general-purpose lanes, 4-lane facilities

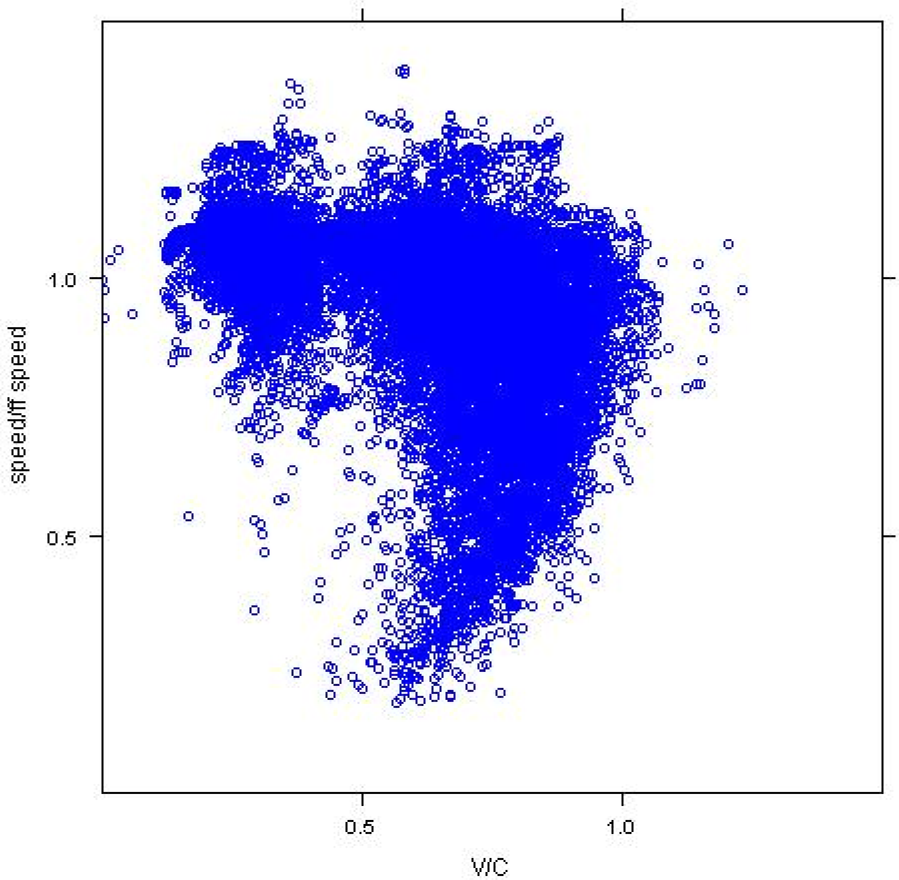


Figure 7-4. Speed/free-flow speed vs. v/c, general-purpose lanes, 5+ lane facilities

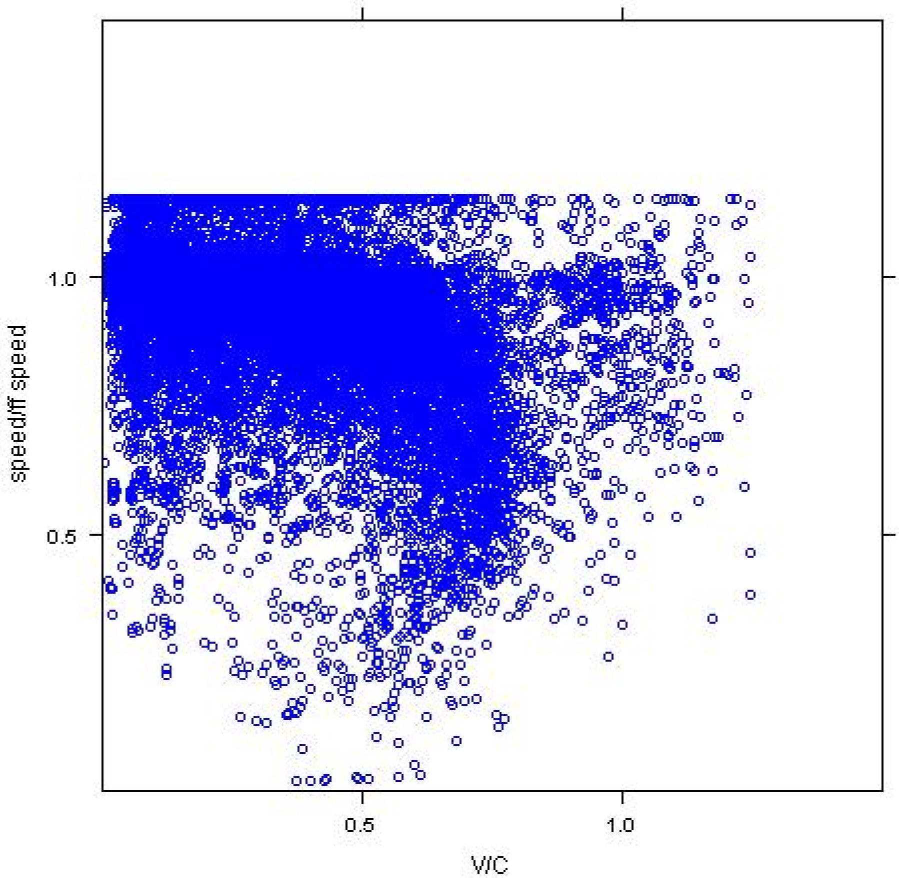


Figure 7-5. Speed/free-flow speed vs. v/c, HOV lanes, 1-lane facilities

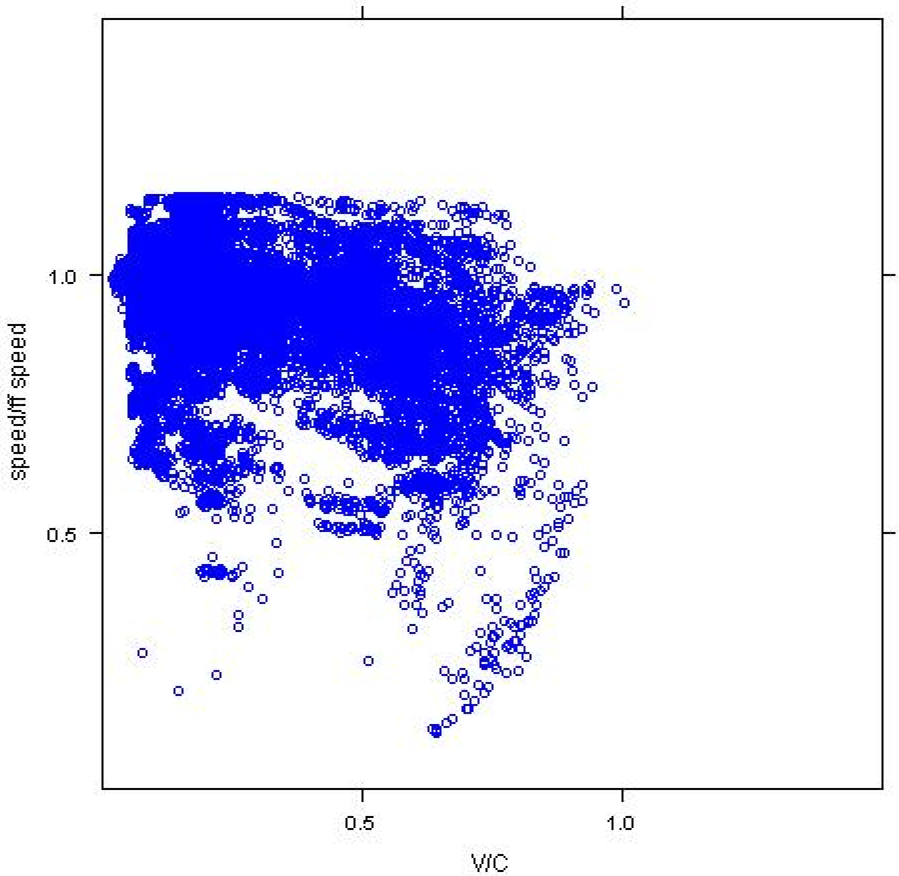


Figure 7-6. Speed/free-flow speed vs. v/c, HOV lanes, 2-lane facilities

The most striking observation from these plots is the set of outliers for the 2-lane mainline facilities (Figure 7-1) that appear in the upper right-hand area of the plot. One possibility is that two different types of facilities could be mixed in the plot, where one has a much higher capacity than the other set; the flat linear set in the upper right-hand area could be at the bottleneck, and the other set could be upstream of the bottleneck. These are probably responsible confounding the model estimation results for 2-lane facilities.

We conducted a further set of model estimations for mainline facilities by grouping the numbers of lanes into two categories: 1) 2 – 3 lanes, and 2) 4+ lanes. For the Urban Business District area type, the parameter estimates for the two different lane categories were not significantly different. The estimated BPR parameters by number of lanes and area type is for this grouping shown in Table 10.

Area type	No. lanes	Sample size	Parameters		Std. errors	
			a	b	a	B
Urban bus dist	All	14,388	0.08	4.62	0.001	0.053
Urban	2 – 3	36,918	0.11	4.81	0.003	0.159
	4+	189,633	0.11	3.81	0.001	0.049
Suburban	2 – 3	33,016	0.18	5.13	0.007	0.172
	4+	89,159	0.12	4.70	0.003	0.092

Note: For all models, min speed/ff speed = 0.8, max speed/ff speed = 1.2, max V/C = 1.1.

Table 7-10. Estimated BPR parameters by number of lanes and area type

These results indicate that at least for the Urban and Suburban area types, the number of lanes has a significant effect on the VDF. For the Urban area type, the a parameter is the same for 2 – 3 lanes and for 4+ lanes; for the Suburban are type, the a parameter is significantly lower for 4+ lanes, indicating that the speed at capacity is closer to free-flow speed for facilities with more lanes. The b parameter is significantly lower for facilities with higher numbers of lanes, indicating a shallower dropoff of speeds at higher V/C ratios.

Conclusions

The a factor from the curve-fitting estimates for all models is significantly smaller than the SCAG value. It is also smaller than the recommended values in the 2000 Highway Capacity Manual. This is because the observed speeds at capacity are nearly equal to the free-flow speeds. The value of a is determined by the following equation:

$$a = \frac{S_{CAP}}{S_{FF}} - 1$$

where S_{CAP} is the speed when flow is at capacity. A visual inspection of the plots in Figure 7-1 through Figure 7-3 shows that the average speed at capacity is about 90% - 95% of the free-flow speed, giving a value for a of about 0.05 – 0.10. The SCAG BPR curve predicts an average speed at capacity of about 46% of the free-flow speed. The estimated values for b are significantly higher than the SCAG value, although they are within the range of recommended values in the 2000 Highway Capacity Manual.

The estimated values for a and b are highly influenced by observations in the V/C range from 0.2 – 0.8. It was not possible to obtain stable V/C estimates using only data for V/C > 0.8. Further adjustment of these curves will be based on review of results of validation runs from the SCAG model. We anticipate that the values for a may need be adjusted higher to reflect incipient breakdown as demand approaches capacity. The required adjustments to b will need to strike a balance between providing a sufficiently sharp dropoff in speeds for V/C > 1 and yet maintaining stability in the feedback process in the model.

The initial model estimation results for HOV facilities produced BPR curves with very shallow slopes. We recommend against using these values, as they would likely result in an over-assignment of traffic to HOV lanes, especially if forecast HOV volumes increase in the future. We therefore suggest that the BPR parameters for HOV lanes be at least equal to those for mainline facilities in the corresponding area types.

As stated in our previous memo, the observed 99th percentile flows indicate that the capacity per lane-hour for the Urban Business District, Urban, and Suburban area types is close to 2,000 per lane-hour. Adjustment for trucks would likely increase this number to close to 2,100 per lane-hour. Our preliminary results therefore do not argue strongly for changing the value currently used by SCAG for freeway capacity.

We conclude with the observation that the number of lanes appears to have a significant effect on the estimated VDF for the Urban and Suburban area types. We therefore recommend that the SCAG model incorporate VDFs that are differentiated by the number of lanes for these area types.

7.3 Model Validation Runs

The new VDF models were coded in the SCAG model and the existing trip tables from the model were re-assigned to the network using the new VDF models. The initial runs showed a large over-assignment to freeways and a large under-assignment to arterials. The high assignment to freeways may have been caused by too low a value for the a parameter; as discussed above in section 5, we had anticipated that the values for a may need be adjusted higher to reflect incipient breakdown as demand approaches capacity. One possible explanation for the low value of the a parameter in the initial estimates is that many of the data points may have been concentrated in the low end of the v/c range.

We discussed the initial validation run results with SCAG, and agreed on a set of revised VDFs based on an analysis of the ratio of speeds at free-flow to those at capacity, using a free-flow speed approximately 5 mph higher than the posted speed limit to account for observed data. We also reviewed the recommended values in the HCM 2000 for a and b values. As discussed above The resulting revised values are shown in Table 7-11, along with what we believe is a reasonable range of values for the parameters.

Facility type	***Revised values***		***Recommended ranges***	
	a	*b*	*a*	*b*
Freeway	0.2	8	0.1 – 0.4	6 – 9
Arterial	0.4	5	0.2 – 0.4	4 – 6

Table 7-11. Revised BPR parameters

The results of the runs are shown for the existing SCAG Akcelik VDF (Akcelik), the initial set of BPR VDFs (BPR 1) and the subsequent set of BPR VDFs (BPR 2) in Note: Data provided by Jim Lam of Caliper Corporation.

Table 7-12. The revised BPR VDFs show a significant improvement over the initial estimated VDFs.

VDF model	Facility group	N counts	Light & medium duty veh				Heavy-duty veh				Total veh				VMT (000)	VHT (000)	Avg speed
			Count (000)	Model (000)	Δ%	RMSE	Count (000)	Model (000)	Δ%	RMSE	Count (000)	Model (000)	Δ%	RMSE			
Akcelik	1	50	8,943	8,938	-0.1	16.9	635	659	3.8	56.7	9,577	9,604	0.3	17.2	7,319	190	38.5
	2	12	375	532	41.8	54.4	12	15	29.5	102.3	387	549	42.1	54.1	108	3	40.6
	3	2	26	26	-2.1	16.0	6	4	-29.5	29.5	32	30	-6.9	14.5	53	1	58.3
	4	137	3,737	3,905	4.5	39.8	179	132	-26.0	132.6	3,916	4,038	3.1	38.8	3,113	112	27.7
	5	129	1,908	1,770	-7.2	43.0	89	54	-40.1	188.4	1,997	1,823	-8.7	41.5	1,361	50	27.5
	6	39	211	182	-13.8	59.0	6	6	-5.7	76.0	218	188	-13.5	59.3	334	12	28.2
	Total	359	14,693	14,534	-1.1	28.9	905	837	-7.6	118.1	15,598	15,379	-1.4	29.3	12,288	368	33.4
BPR 1	1	50	8,943	10,374	16.0	28.8	635	610	-3.8	58.0	9,577	10,998	14.8	28.4	7,885	150	52.7
	2	12	375	219	-41.6	52.1	12	14	18.6	64.5	387	237	-38.6	50.2	4	0	65.0
	3	2	26	23	-12.0	28.5	6	3	-43.4	43.8	32	26	-17.6	26.8	46	1	62.8
	4	137	3,737	3,689	-1.3	42.9	179	103	-42.2	137.0	3,916	3,794	-3.1	41.8	2,824	75	37.6
	5	129	1,908	1,381	-27.6	58.2	89	37	-58.9	193.2	1,997	1,417	-29.0	56.9	1,109	31	36.3
	6	39	211	142	-32.8	65.6	6	3	-46.6	76.2	218	145	-33.2	65.7	206	6	35.3
	Total	359	14,693	15,136	3.0	44.3	905	737	-18.6	120.3	15,598	15,890	1.9	43.8	12,074	262	46.1
BPR 2	1	50	8,943	9,672	8.2	19.4	635	802	26.4	65.3	9,577	10,474	9.4	20.6	7,773	167	46.6
	2	12	375	512	36.4	52.1	12	19	62.6	217.0	387	530	37.2	54.4	92	2	58.1
	3	2	26	24	-7.9	23.1	6	5	-20.2	23.9	32	29	-10.1	22.5	51	1	62.6
	4	137	3,737	3,620	-3.1	38.1	179	135	-24.4	132.4	3,916	3,755	-4.1	37.3	2,854	85	33.5
	5	129	1,908	1,526	-20.0	49.4	89	52	-41.5	190.8	1,997	1,578	-21.0	48.2	1,224	38	32.3
	6	39	211	152	-27.8	66.1	6	5	-24.3	73.2	218	157	-27.7	66.1	250	8	32.7
	Total	359	14,693	14,649	-0.3	29.8	905	975	7.7	131.4	15,598	15,624	0.2	31.6	12,242	300	40.8

Note: Data provided by Jim Lam of Caliper Corporation.

Table 7-12. Comparative validation run results for three sets of VDFs

7.4 Conclusions and Recommendations

This study was intended to provide SCAG with a revised set of volume-delay functions and a revised truck model. Products of this study include the following:

- A new set of arterial speed surveys at 24 sites throughout the SCAG region. These sites, combined with the 8 sites surveyed in Los Angeles County as part of the Phase 1 study, provide SCAG with a total of 32 sites with speed and volume data to support further work on refining arterial VDFs.

- A set of PeMS data used to estimate the freeway VDFs.

- Initial and revised estimates of arterial and freeway VDFs.

- A preliminary investigation of truck speeds, and an analytical framework that can be used for further work on truck speeds.

We have recommended that BPR VDFs be used for both arterials and freeways, with ranges for the parameter values as discussed in section 7.3. The preliminary validation results for the revised set of VDFs indicate that they appear to perform adequately. We recommend that the following be done as part of further testing of the VDFs:

- Review capacities coded for arterials in area types 3 and 5 (Urban Business District, and Suburban), especially for two-lane arterials (single lane in each direction). They tend to be 20% to 50% low.

- Review free-flow speeds for freeways. Currently SCAG uses posted speed as the free-flow speed, but PeMS observations show a large number of data points with speeds greater than the posted speed. We recommend that free-flow speeds on freeways be increased by 5 mph to account for this.

- Further validation work should include a revision of the trip distribution friction factors using the new VDFs to calculate travel times.

Appendix A – Driver Instructions for Arterial Speed Surveys

The following pages contain driver instructions for using the GPS units for the arterial speed surveys. This is a copy of the driver instructions provided by Carter-Burgess.

DAILY ROUTINE

REMINDER: AS YOU DRIVE, DO NOT MONITOR THE EQUIPMENT OR REACT TO ANY ERROR MESSAGES. ONLY DO THIS WHILE STOPPED AT A SIGNAL OR AFTER PULLING OFF THE ROAD.

START-UP (BEFORE AM AND PM RUNS)

- Make sure cars are gassed up from previous day (should be done before shutting down each day)
- Make sure Set-up is complete (PDA (Dell Axim), GPS, antenna, voice recorder , chargers, and folder)
- Proceed to vehicle to install equipment
    - With the GPS oriented such that the two lights are facing you, flip the switch on the right side to on (2 lights on the front should come on (if top lights come on, turn that switch off and try the other)
    - Place GPS on dash of vehicle
    - When the GPS has a fix on the satellites, the right light will flash green
    - Turn on Dell PDA

1. PDA

    a. Turn on PDA by pressing the silver button
    b. Start GPS Travel Speed Program by pressing the bottom left silver button on the PDA. Wait 10 seconds for the program to start. DO NOT PUSH THE BUTTON AGAIN WITHOUT WAITING 10 SECONDS.
    c. The PDA will acquire the Bluetooth signal from the GPS in 2-3 minutes.
    d. If prompted with a question stating that the GPS (HI-406BT) would like to connect to the device…ALWAYS CLICK **NO** TO THIS QUESTION!!
    e. Make sure the Latitude and Longitude fields display values and Fix Method field shows "3D" value. If the values are blank then wait 2 to 3 minutes more for those to fill in. If they are still blank then move to a different location where they are fewer obstructions.

Click on the “Run Data” tab in the bottom middle of the screen.

f. The GPS time display should show the current time.
g. If the back ground of time is in Red color as shown in the figure below, then check to make sure PDA time zone setting are correct and you are driving in the correct time period..
h. If the display time is not the correct local time, then exit program by pushing “Exit” at the bottom right of the screen to return to the main screen. On this screen tap the line that shows the time and date. This will bring a menu up that allows you to set the correct time zone (US central) and time.
i. Restart the travel time program (step a) and this should correct the time.
j. Click the “Route Data” tab in the bottom middle of the screen
k. Select either Route or Route Identifier and the other field will get automatically populated.
l. Driver name must be selected before starting the run.

m. Select the "Run Data" tab in the bottom left of the screen
n. Make sure the "Video is being recorded" toggle is not checked
o. You are now ready to begin your run. Make sure you are in proper position prior to your prescribed starting location and if so, press "Start Run" in the middle top of the screen.
p. Confirm that the number in the "Points" window is increasing each second
q. Begin Driving.

r. After crossing the last intersection on your assigned route, press the "STOP" button at the top of the screen to stop collecting data.

REMINDER: AS YOU DRIVE, DO NOT MONITOR THE EQUIPMENT OR REACT TO ANY ERROR MESSAGES. ONLY DO THIS WHILE STOPPED AT A SIGNAL OR AFTER PULLING OFF THE ROAD.

NEW RUN

1. PDA
   - o After selecting STOP from the previous run, select the "Route Data" on the bottom center of the screen and select the new route.
   - o Return to the "Run Data" tab and you are ready to push "Start Run" to begin your run.

2. REPEAT STEPS UNTIL ALL RUNS FOR THAT PERIOD ARE COMPLETE

SHUT-DOWN (AFTER MID-DAY AND PM RUNS)

IF RUNS ARE COMPLETE

PDA

- o Select EXIT at the bottom right corner of the screen
- o Turn OFF (top middle silver button)

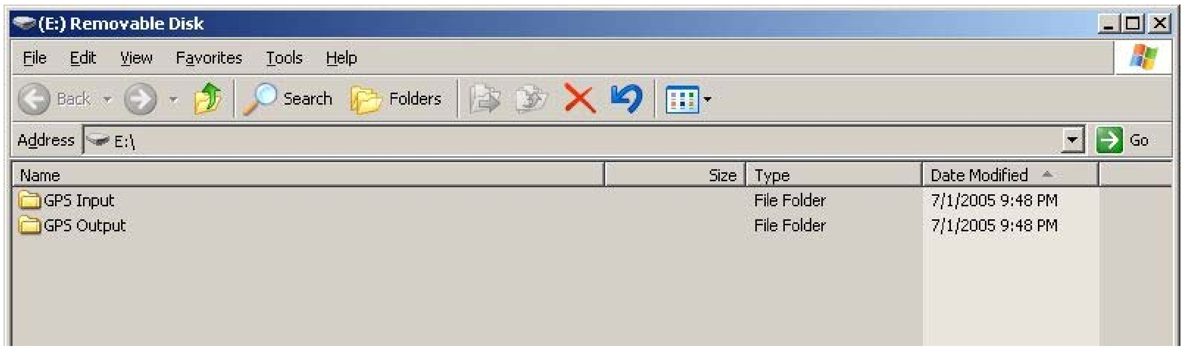
GPS

- o Turn off switch on the right side of the GPS

1. If returning from a Mid-day run, be sure to fill up the car with gas before parking
2. Make sure all equipment is turned OFF (PDA, GPS, voice recorder) and return to container.
3. Plug in GPS and PDA for charging between runs

EXPORTING DATA FROM GPS MEMORY CARD

1. Push down on the SD card in the PDA gently as if pushing a button. This will pop the SD card out. A click can also be heard when the SD card is ready to come out.
2. Place the SD Card in the SD card reader. The side of the card with a "notch" cut off will enter the card reader. The card's capacity label will be on top when inserted properly.



3. Place the card reader along with the SD card in your computer's USB drive.
4. This should launch a window with the contents of the card being displayed. Something like this:
5. If the window does not open up automatically after 10 seconds, open "My Computer" and check to see if any new drives have been added to your computer. The USB reader will show up as a new drive. If not, restart your machine or try on another computer.
6. Right click on "GPS Output" folder, copy it, and paste the contents on your local hard-disk.
7. Zip the folder on your local drive; include driver's name and current date on the zip file name using dashes and underscores as necessary. (Example: "Steve_Taylor_ March_14_ 2007.zip")
8. Return to the SD Card in Explorer and delete the contents after confirming that you successfully copied them to your computer.
9. In your system-tray double click on the "Safely Remove Hardware" icon, select "USB Mass storage drive" and click stop. You can now remove the card reader.
10. Remove the SD card from the card reader and place it back in the PDA. The shortest side will go in first. Push it down until you hear a click and the SD card is completely in the PDA.

TROUBLSHOOTING GUIDE

REMINDER: AS YOU DRIVE, DO NOT MONITOR THE EQUIPMENT OR REACT TO ANY ERROR MESSAGES. ONLY DO THIS WHILE STOPPED AT A SIGNAL OR AFTER PULLING OFF THE ROAD.

1. GPS Errors
    a. Wait at least 2 minutes for the GPS to gather satellite info.
    b. If the HDOP is too high (you will get an error message on the PDA). Pull off at the next intersection and return to a location prior to when HDOP went up and wait for up to 20 minutes or so for it to return to a good position. When it drops, begin a new run from that location and continue.
    c. If you have followed all the instructions and feel that something is "locked up" and not running, reset the PDA by pushing your stylus into the "reset button" on the back of the PDA.
    d. Typically, for most common issues when the PDA is not reacting like you would expect, the reset button clears those and allows you to restart the program as usual.
    e. Check to make sure SD Card is not locked/write-protected
    f. If nothing seems to correct the problem or the PDA does not respond to your attempts to push buttons, check the key lock on the left side of the PDA. Move it down to unlock.

Appendix B – Speed Survey Data Dictionary

Note: the following is a copy of the speed survey data dictionary provided by Carter-Burgess.

Data Type Synonyms for SQL Server and MS Access

The fields described in this data dictionary are based on SQL server data types. If the data has been exported to MS Access, use the following table to determine the data type:

Access	SQL
date/time	datetime
double	float, decimal
long integer	Integer (int)
text	varchar, char

Legend

The following table describes the symbols and variables used in formulas and tables throughout this document:

Symbol	Description
*	Primary Key
i	Current record
n	Total records

*Note: The field names described in this document are for feature classes, tables and views. Exporting feature classes to ESRI shape files will result in field names truncated at 8 characters.

Features

The following are feature classes that are stored inside of a relational database management system (SQL Server) or exported to a personal geodatabase (MS Access). The prefix ‘sde’ indicates a feature class, which contains spatial data and route measures.

Feature	Field Name	Data Type	Description
Route			Route PolylineM feature. Base routes for directional Linear Reference System
	ObjectId*	Integer	Object Identifier where each row is an object (AutoNumber)
	RouteId*	Integer	Route Identifier
	RouteName	varchar	Directional Route Name
	Shape	Integer	ESRI Shape Identifier
	StudyID	Integer	Unique identifier for the project
Intersection			Intersection point feature. An intersection point exists for each route. Two consecutive intersection points on a route define intersection segments (ISseg)
	ObjectId*	Integer	Object Identifier where each row is an object (AutoNumber)
	Control	varchar	Intersection Control: Signal Stop Roundabout Cross Street TWSC – Two Way Stop Control AWSC – All Way Stop Control Signal - No Stop – T intersection; continuous green Ped Signal SPUI – Single Point Urban Intersection Cross Section Jurisdiction External
	Intersection	varchar	Name of intersecting street
	IntId	integer	Intersection location identifier. Intersection points for all routes at the same location have the same IntId
	Measure	float	Route Measure (ft)
	RouteId	integer	Route Identifier for sdeRoute
	Shape	Integer	ESRI Shape Identifier

Event Tables

The following table describes the tabular data and views of the data stored in the database. Tables containing route identifiers and measures can also be viewed spatially as point or line events using linear referencing and can be exported to feature classes. The prefix ‘tbl’ indicates tabular data while the prefix ‘vw’ indicates a view of the data.

Table	Field Name	Data Type	Description
IntersectionSegment			Intersection Segments
	ISsegId*	integer	Intersection Segment Identifier based on consecutive intersection segments along a route. $ISsegID_i = (RouteID * 1000$
	ISseg	varchar	[Upstream Intersection] to [Downstream Intersection]
	RouteId	integer	Route Identifier for sdeRoute
	StartM	decimal	Upstream route measure
	EndM	decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data
	Control	varchar	Intersection Control: Signal Cross Street TWSC – Two Way Stop Control AWSC – All Way Stop Control Signal - No Stop – T intersection; continuous green Ped Signal SPUI – Single Point Urban Intersection Cross Section Jurisdiction

Table	Field Name	Data Type	Description
	wavgSL	decimal	Weighted Average Speed Limit. Weighted by length of speed zones where the speed limit changes between intersections $$wavgSL = \frac{\sum_i d_i}{\sum_i \frac{d_i}{SL_i}}$$ where: SL = Speed Limit d = Length of Speed Limit zone
	SZwavgSL	integer	School Zone weighted average speed limit. wavgSL including the length of the school zone and school zone speed within the intersection segment
	FFTT	decimal	Free Flow Travel Time. $$FFTT = \frac{EndM - StartM}{wavgSL}$$
	SZFFTT	decimal	School Zone Free Flow Travel Time. $$SZFFTT = \frac{EndM - StartM}{SZwavgSL}$$
	IntSegId*	integer	Intersection Segment Identifier based on intersection IntIds: $$IntSegID_i = (IntID_{Upstream} * 10000$$
	IntersectionSummarySegmentId	Integer	Identifier of the intersection summary segment that this intersection segment is contained by
SpeedLimitSegment			Speed Limit Segments
	SLsegId*	integer	Speed Limit Segment Identifier based on consecutive speed limit changes along a route. $$SLsegID_i = (RouteID * 100($$

Table	Field Name	Data Type	Description
	SpeedLimit	integer	Speed Limit (MPH)
	RouteId	integer	Route Identifier for sdeRoute
	StartM	decimal	Upstream route measure
	EndM	decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data
SchoolZoneSegment			School Zone Segments. Used to calculate free flow travel time and delay when the school zone is active
	SZsegId*	integer	School Zone Segment Identifier
	RouteId	integer	Route Identifier for sdeRoute
	SZSpeedLimit	integer	School Zone Speed Limit
	AMBeginTime	datetime	School Zone Begin Time for the AM
	AMEndTime	datetime	School Zone End Time for the AM
	PMBeginTime	datetime	School Zone Begin Time for the PM
	PMEndTime	datetime	School Zone End Time for the PM
	Comment	varchar	Record Comments
	StartM	decimal	Upstream route measure
	EndM	decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data
TimePeriodSegment			End to end driving limits on a route for each time period
	StudyId	integer	Study Identifier

Table	Field Name	Data Type	Description
	TimePeriodId	integer	Time Period Identifier. Several TimePeriodId's can be within one PeakPeriodId
	RouteId	Integer	Route Identifier for sdeRoute
	StartIntId	integer	Upstream intersection location identifier
	EndIntId	integer	Downstream intersection location identifier
	Route	varchar	Directional Route Name
	StartIntersection	Varchar	Upstream intersection of the summary segment
	EndIntersection	Varchar	Downstream intersection of the summary segment
	StartM	Decimal	Upstream route measure
	EndM	Decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data
	StartTime	varchar	Time Period Start Time
	EndTime	varchar	Time Period End Time
vwTimePeriodSummarySegmentAverage			Summary segments between major intersections (one or more IntersectionSegment segments)
	IntersectionSummarySegmentId*	integer	Record Identifier (AutoNumber)
	RouteId	integer	Route Identifier for sdeRoute
	StartIntId	integer	Upstream intersection location identifier
	EndIntId	integer	Downstream intersection location identifier
	StartM	decimal	Upstream route measure
	EndM	decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data

Table	Field Name	Data Type	Description
	RouteName	varchar	Directional Route Name from sdeRoute
	StartIntersection	varchar	Upstream intersection name
	EndIntersection	varchar	Downstream Intersection
	wavgSL	decimal	Weighted Average Speed Limit. Weighted by length of speed zones where the speed limit changes between intersections $$wavgSL = \frac{\sum_i d_i}{\sum_i \frac{d_i}{SL_i}}$$ where: SL = Speed Limit d = Length of Speed Limit zone
	SZwavgSL	integer	School Zone weighted average speed limit. wavgSL including the length of the school zone and school zone speed within the intersection segment
	FFTT	decimal	Free Flow Travel Time. $$FFTT = \frac{EndM - StartM}{wavgSL}$$
	SZFFTT	decimal	School Zone Free Flow Travel Time. $$SZFFTT = \frac{EndM - StartM}{SZwavgSL}$$
vwDatafile			Unique Run Identifier. One record exists for each route the run traverses.
	DatafileId*	integer	Datafile table identifier (AutoNumber)
	StudyId	integer	Study Identifier

Table	Field Name	Data Type	Description
	Datafile	varchar	Travel Run Identifier [1234][5][67][8] [1234]=RouteId [5] = PeakPeriodId [67] = EmployeeId [8] = Character [A-Z] to prevent duplicate datafiles
	OriginalDatafile	varchar	Original Datafile from field data collection
	GISFile	varchar	The shapefile that contains the run
	RouteId	integer	Route Identifier for sdeRoute
	Route	varchar	Directional Route Name
	RunId	varchar	Run identifier by route [Datafile][RouteId]
	GPSDate	datetime	GPS Date
	minTime	datetime	Start time of run
	maxTime	datetime	End time of run
	PeakPeriodId	integer	Peak Period Identifier. Several TimePeriodId's can be within one PeakPeriodId 1 = AM 2 = Mid-Day (MD) 3 = PM
	TimePeriodId	integer	Time Period Identifier. Several TimePeriodId's can be within one PeakPeriodId
	StartTime	varchar	Time Period Start Time
	EndTime	varchar	Time Period End Time
	PeakPeriod	varchar	Peak Period, AM, Mid-Day (MD), PM
	AvgTMS	float	Average Time Mean Speed (MPH). The arithmetic average of 1 second GPS speed within the segment.

Table	Field Name	Data Type	Description
	AvgSMS	float	Average Space Mean Speed (MPH). The average speed based on the travel time over the segment. $avgSMS = \frac{\max Measure - \min M}{\max Time - \min Ti}$
	avgBearing	float	Average GPS Bearing for run
	avgPDOP	float	Average GPS Position Dilution of Precision for run.
	PositionCount	Integer	The total number of GPS positions within the run
	UserId	integer	Driver Record Identifier
	StartM	float	Minimum route measure
	EndM	float	Maximum route measure
	Offset	integer	Offset from route for display as GIS event data
tblExclude			Specific exclusions from tables and queries based on vwDatafile and vwISsegDatafile. Summary data is excluded from the result tables but the GPS data still exists within tblSpeed. Data is excluded based on the amount of detail provided (if only a datafile is specified then the entire datafile is excluded)
	ExcludeId*	integer	Exclusion table Identifier (AutoNumber)
	StudyId	integer	Study Identifier
	GISFile	varchar	The shapefile that contains the run
	Datafile	varchar	Travel Run Identifier [1234][5][67][8] [1234]=RouteId [5] = PeakPeriodId [67] = EmployeeId [8] = Character [A-Z] to prevent duplicate datafiles
	RouteId	integer	Route Identifier for sdeRoute

Table	Field Name	Data Type	Description
	IntSegId	integer	Intersection Segment Identifier based on intersection IntIds: $IntSegID_i = (IntID_{Upstream} * 10000$
	StartM	decimal	Upstream route measure
	EndM	decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data
	Comment	varchar	Reason for excluding data
	CommentCategory	varchar	Exclusion Category: 1: Accident 2: Construction 3: Emergency Services 4: Incident 5: Operations 6: Rail Crossing 7: School Zone 8: School Bus 9: Weather 10: GPS Error 11: Driver Error 12: GPS Obstruction 13: Other
vwISsegDatafile			Summary of each travel run by Intersection Segment
	STPISDQCId*	Integer	Unique identifier
	DatafileId	Integer	Unique Run Identifier. One record exists for each route the run traverses
	StudyId	integer	Study Identifier
	GISFile	varchar	The shapefile that contains the GPS points
	Datafile	varchar	Travel Run Identifier [1234][5][67][8] [1234]=RouteId [5] = PeakPeriodId [67] = EmployeeId [8] = Character [A-Z] to prevent duplicate datafiles

Table	Field Name	Data Type	Description
	RouteId	Integer	Route Identifier for sdeRoute
	IntSegId	integer	Intersection Segment Identifier based on intersection IntIds: $IntSegID_i = (IntID_{Upstream} *10000$
	PeakPeriodId	integer	Peak Period Identifier 1 = AM 2 = Mid-Day (MD) 3 = PM
	TimePeriodId	integer	Time Period Identifier. Several TimePeriodId's can be within one PeakPeriodId
	StudyName	Varchar	Name of the study during which this data was collected
	Route	varchar	Directional Route Name
	ISseg	varchar	[Upstream Intersection] to [Downstream Intersection]
	StartM	Decimal	Upstream route measure
	EndM	Decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data
	StartTime	varchar	Time Period Start Time
	EndTime	varchar	Time Period End Time
	PeakPeriod	varchar	Peak Period, AM, Mid-Day (MD), PM
	MinTime	datetime	Minimum GPS time within IndSegId
	MaxTime	datetime	Maximum GPS time within IndSegId
	MinM	decimal	Minimum route measure within IndSegId
	MaxM	decimal	Maximum route measure within IndSegId

Table	Field Name	Data Type	Description
	AvgSpeed	float	Average Speed (MPH) AvgSMS if (EndM-StartM) ≥ 1000 ft or AvgTMS is NULL AvgTMS if (EndM-StartM) < 1000 ft
	AvgSMS	float	Average Space Mean Speed (MPH). The average speed based on the travel time over the segment. $avgSMS = \frac{\max Measure - \min M}{\max Time - \min Ti}$
	AvgTMS	float	Average Time Mean Speed (MPH). The arithmetic average of 1 second GPS speed within the segment.
	RunningSpeed	float	The arithmetic average of 1 second GPS speed points excluding stop delay (> 3 MPH)
	wavgSL	decimal	Weighted Average Speed Limit. Weighted by length of speed zones where the speed limit changes between intersections $wavgSL = \frac{\sum_i d_i}{\sum_i \frac{d_i}{SL_i}}$ where: SL = Speed Limit d = Length of Speed Limit zone
	IsSchoolZoneActive	bit	0 = No (school zone inactive during this run) 1 = Yes (school zone active during this run)
	TravelTime (TT)	Float	Travel Time (sec) = MaxTime - MinTime
	FreeFlowTravelTime (FFTT)	float	Free Flow Travel Time (sec). $FFTT = \frac{\min Time - \max Time}{wavgSL}$
	RunningTime	float	Running Time (sec) = TravalTime - StopDelay

Table	Field Name	Data Type	Description
	QueueMeasure	decimal	Route measure at the first point the vehicle stopped within ISseg (< 3 MPH)
	QueuePosition	decimal	Position in queue from downstream intersection (ft) = EndM – QueueMeasure
	SegmentDelay	Decimal	Segment Delay (sec) FFTT-TT
	StopDelay	Decimal	Stop Delay (sec) Amount of time speed is < 3 MPH
	MidBlockDelay	decimal	Mid-Block delay (sec) $(Length)\times\left(\frac{1}{RunningSpeed}-\frac{}{FreeF}\right.$
	ControlDelay	Decimal	Control Delay (sec) = SegmentDelay - MidBlockDelay
	Control	varchar	Intersection control type (tblISseg.Control)
	LOS	char(1)	Level Of Service from the Highway Capacity Manual. Value is from one of the following tables depending on the downstream control: tblSignalLOS tblUnSignalLOS tblUrbanLOS
	LengthFt	Decimal	Segment Length (ft) = EndM – StartM
vwTimePeriodISseg			Data collection status by time period for each intersection segment (tblISseg) included in the study
	StudyId	integer	Study Identifier
	PeakPeriodId	integer	Peak Period Identifier 1 = AM 2 = Mid-Day (MD) 3 = PM
	TimePeriodId	integer	Time Period Identifier. Several TimePeriodId’s can be within one PeakPeriodId

Table	Field Name	Data Type	Description
	RouteId	Integer	Route Identifier for sdeRoute
	IntSegId	integer	Intersection Segment Identifier based on intersection IntIds: $IntSegID_i = (IntID_{Upstream} * 10000$
	ISsegId	integer	Intersection Segment Identifier based on consecutive intersection segments along a route. $ISsegID_i = (RouteID * 1000$
	StartM	Decimal	Upstream route measure
	EndM	Decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data
	RequiredRuns	Integer	The number of required runs as specified in tblTimePeriod
	CompletedRuns	Integer	The count of the number of runs already completed for this time
	RemainingRuns	Integer	RequiredRuns – Completed Runs. Set to zero if the number of completed runs is greater than the required runs.
	StudyName	Varchar	Name of the study during which this data was collected
	Route	varchar	Directional Route Name
	ISseg	varchar	[Upstream Intersection] to [Downstream Intersection]
	StartTime	varchar	Time Period Start Time
	EndTime	varchar	Time Period End Time
	PeakPeriod	varchar	Peak Period, AM, Mid-Day (MD), PM
vwTimePeriodISsegAverage			Summary of all travel runs within an intersection segment by time period
	StudyTimePeriodRouteSegmentId*	Integer	Unique identifier

Table	Field Name	Data Type	Description
	StudyId	integer	Study Identifier
	RouteId	Integer	Route Identifier for sdeRoute
	IntSegId	integer	Intersection Segment Identifier based on intersection IntIds: $IntSegID_i = (IntID_{Upstream} *10000$
	PeakPeriodId	integer	Peak Period Identifier 1 = AM 2 = Mid-Day (MD) 3 = PM
	TimePeriodId	integer	Time Period Identifier. Several TimePeriodId's can be within one PeakPeriodId
	StudyName	Varchar	Name of the study during which this data was collected
	Route	varchar	Directional Route Name
	ISseg	varchar	[Upstream Intersection] to [Downstream Intersection]
	StartM	Decimal	Upstream route measure
	EndM	Decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data
	StartTime	varchar	Time Period Start Time
	EndTime	varchar	Time Period End Time
	PeakPeriod	varchar	Peak Period, AM, Mid-Day (MD), PM
	Runs	Integer	The count of runs this record summarizes
	Stops	Integer	The count of runs that incur stop delay (< 3 MPH) within a segment. Even if a vehicle stops more than once on one run within a segment, it is counted as one stop
	pctStops	Float	Percent Stops = Stops/Runs
	AvgSpeed	float	Average of vwISsegDatafile.AvgSpeed (MPH)

Table	Field Name	Data Type	Description
	StdSpeed	Float	Standard deviation of vwISsegDatafile.AvgSpeed (MPH)
	Error90	Float	90% Confidence Interval based on the t-distribution. There is a 90% probability that the average speed is between [avgSpeed – Error90] & [avgSpeed + Error90]
	Error85	Float	85% Confidence Interval based on the t-distribution. There is a 85% probability that the average speed is between [avgSpeed – Error85] & [avgSpeed + Error85]
	AvgSMS	float	Average Space Mean Speed (MPH). Average of vwISsegDatafile.AvgSMS
	AvgTMS	float	Average Time Mean Speed (MPH. Average of vwISsegDatafile.AvgTMS
	avgRunningSpeed	float	The arithmetic average of 1 second GPS speed points excluding stop delay (> 3 MPH)
	wavgSL	decimal	Weighted Average Speed Limit. Weighted by length of speed zones where the speed limit changes between intersections $wavgSL = \frac{\sum_i d_i}{\sum_i \frac{d_i}{SL_i}}$ where: SL = Speed Limit d = Length of Speed Limit zone
	ActiveSchoolZoneRuns	bit	Count of runs with vwISsegDatafile.IsSchoolZoneActive = true
	avgTT	Float	Average of vwISsegDatafile.TravelTime (sec)
	avgFFTT	Float	Average of vwISsegDatafile.FreeFlowTravelTime (sec)
	avgRunningTime	float	vwISsegDatafile.avgRunningTime (sec)

Table	Field Name	Data Type	Description
	minQMeasure	float	Minimum vwISsegDatafile.QueueMeasure
	avgQMeasure	float	Average vwISsegDatafile.QueueMeasure
	maxQMeasure	float	Maximum vwISsegDatafile.QueueMeasure
	minQPosition	float	Minimum vwISsegDatafile.QueueMeasure
	avgQPosition	float	Average vwISsegDatafile.QueueMeasure
	maxQPosition	float	Maximum vwISsegDatafile.QueueMeasure
	pctPostedSpeed	Float	AvgSpeed/wavgSL
	avgSegmentDelay	Float	Average vwISsegDatafile.SegmentDelay (sec)
	avgStopDelay	Float	Average vwISsegDatafile.StopDelay (sec)
	avgMidBlockDelay	Float	Average vwISsegDatafile.MidBlockDelay (sec)
	avgControlDelay	Float	Average vwISsegDatafile.ControlDelay (sec)
	avgSegDelayMi	Float	avgSegDelay/Length (sec/mile)
	Control	varchar	Intersection control type (tblISseg.Control)
	LOS	char(1)	Level Of Service from the Highway Capacity Manual. Value is from one of the following tables depending on the downstream control: tblSignalLOS tblUnSignalLOS tblUrbanLOS
	LengthFt	Decimal	Segment Length (ft) = EndM – StartM

Table	Field Name	Data Type	Description
vwTimePeriodSegmentAverage			Summary of all travel runs for a time period within each time period segment, or end to end route summary by time period (see vwTimePeriodSegment). Calculated by aggregating results from vwTimePeriodISsegAverage
	StudyTimePeriodRouteSegmentId*	Integer	Unique identifier
	StudyId	integer	Study Identifier
	RouteId	Integer	Route Identifier for sdeRoute
	PeakPeriodId	integer	Peak Period Identifier 1 = AM 2 = Mid-Day (MD) 3 = PM
	TimePeriodId	integer	Time Period Identifier. Several TimePeriodId's can be within one PeakPeriodId
	StudyName	Varchar	Name of the study during which this data was collected
	Route	varchar	Directional Route Name
	StartIntersection	Varchar	Upstream intersection of the summary segment
	EndIntersection	Varchar	Downstream intersection of the summary segment
	StartM	Decimal	Upstream route measure
	EndM	Decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data
	StartTime	varchar	Time Period Start Time
	EndTime	varchar	Time Period End Time
	PeakPeriod	varchar	Peak Period, AM, Mid-Day (MD), PM
	avgRuns	Integer	The average count of runs within each intersection segment (vwTimePeriodISsegAverage.Runs)

Table	Field Name	Data Type	Description
	totalStops	Integer	The count of vwTimePeriodISsegAverage.Stops
	avgStopsPerRun	Float	totalStops/avgRuns
	avgPctStops	Float	Average of vwTimePeriodISsegAverage.Runs / vwTimePeriodISsegAverage.Stops
	wavgSpeed	float	Distance weighted average vwTimePeriodISsegAverage.AvgSMS (MPH)
	wavgSMS	float	Distance weighted average vwTimePeriodISsegAverage.AvgTMS (MPH)
	wavgTMS	float	Distance weighted average vwTimePeriodISsegAverage.AvgSpeed (MPH)
	wavgRunningSpeed	float	Distance weighted average vwTimePeriodISsegAverage.AvgRunningSpeed (MPH)
	wavgSL	decimal	Weighted Average Speed Limit. Weighted by length of speed zones where the speed limit changes between intersections $$wavgSL = \frac{\sum_i d_i}{\sum_i \frac{d_i}{SL_i}}$$ where: SL = Speed Limit d = Length of Speed Limit zone
	EndtalActiveSchoolZoneRuns	bit	Count of runs with vwISsegDatafile.IsSchoolZoneActive = true
	TotalAvgTT	Float	Sum of vwTimePeriodISsegAverage.AvgTT (sec)
	TotalAvgFFTT	Float	Sum of vwTimePeriodISsegAverage.AvgFFTT (sec)

Table	Field Name	Data Type	Description
	TotalAvgRunningTime	float	Sum of vwTimePeriodISsegAverage.AvgRunningTime (sec)
	wavgPctPostedSpeed	Float	wavgSpeed/wavgSL
	TotalAvgSegmentDelay	Float	Sum of vwTimePeriodISsegAverage.AvgSegmentDelay (sec)
	TotalAvgStopDelay	Float	Sum of vwTimePeriodISsegAverage.AvgStopDelay (sec)
	TotalAvgMidBlockDelay	Float	Sum of vwTimePeriodISsegAverage.AvgStopDelay (sec)
	TotalAvgControlDelay	Float	Sum of vwTimePeriodISsegAverage.AvgControlDelay (sec)
	avgSegmentDelayPerMile	Float	TotalAvgSegDelay/Length (sec/mile)
	LengthFt	Decimal	Segment Length (ft) = EndM – StartM
vwStudyTimePeriodISSegAverage			Summary of all travel runs for a time period within each vwIntersectionSummarySegment. Calculated by aggregating results from vwTimePeriodISsegAverage
	StudyTimePeriodRouteSegmentId*	Integer	Unique identifier
	IntersectionSummarySegmentId*	integer	Record Identifier (AutoNumber)
	StudyId	integer	Study Identifier
	RouteId	Integer	Route Identifier for sdeRoute
	PeakPeriodId	integer	Peak Period Identifier 1 = AM 2 = Mid-Day (MD) 3 = PM
	TimePeriodId	integer	Time Period Identifier. Several TimePeriodId's can be within one PeakPeriodId

Table	Field Name	Data Type	Description
	StudyName	Varchar	Name of the study during which this data was collected
	Route	varchar	Directional Route Name
	StartIntersection	Varchar	Upstream intersection of the summary segment
	EndIntersection	Varchar	Downstream intersection of the summary segment
	StartM	Decimal	Upstream route measure
	EndM	Decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data
	StartTime	varchar	Time Period Start Time
	EndTime	varchar	Time Period End Time
	PeakPeriod	varchar	Peak Period, AM, Mid-Day (MD), PM
	avgRuns	Integer	The average count of runs within each intersection segment (vwTimePeriodISsegAverage.Runs)
	totalStops	Integer	The count of vwTimePeriodISsegAverage.Stops
	avgStopsPerRun	Float	totalStops/avgRuns
	avgPctStops	Float	Average of vwTimePeriodISsegAverage.Runs / vwTimePeriodISsegAverage.Stops
	wavgSpeed	float	Distance weighted average vwTimePeriodISsegAverage.AvgSMS (MPH)
	wavgSMS	float	Distance weighted average vwTimePeriodISsegAverage.AvgTMS (MPH)
	wavgTMS	float	Distance weighted average vwTimePeriodISsegAverage.AvgSpeed (MPH)
	wavgRunningSpeed	float	Distance weighted average vwTimePeriodISsegAverage.AvgRunningSpeed (MPH)

Table	Field Name	Data Type	Description
	wavgSL	decimal	Weighted Average Speed Limit. Weighted by length of speed zones where the speed limit changes between intersections $$wavgSL = \frac{\sum_i d_i}{\sum_i \frac{d_i}{SL_i}}$$ where: SL = Speed Limit d = Length of Speed Limit zone
	TotalActiveSchoolZoneRuns	bit	Count of runs with vwISsegDatafile.IsSchoolZoneActive = true
	TotalAvgTT	Float	Sum of vwTimePeriodISsegAverage.AvgTT (sec)
	TotalAvgFFTT	Float	Sum of vwTimePeriodISsegAverage.AvgFFTT (sec)
	TotalAvgRunningTime	float	Sum of vwTimePeriodISsegAverage.AvgRunningTime (sec)
	wavgPctPostedSpeed	Float	wavgSpeed/wavgSL
	TotalAvgSegmentDelay	Float	Sum of vwTimePeriodISsegAverage.AvgSegmentDelay (sec)
	TotalAvgStopDelay	Float	Sum of vwTimePeriodISsegAverage.AvgStopDelay (sec)
	TotalAvgMidBlockDelay	Float	Sum of vwTimePeriodISsegAverage.AvgStopDelay (sec)
	TotalAvgControlDelay	Float	Sum of vwTimePeriodISsegAverage.AvgControlDelay (sec)
	avgSegmentDelayPerMile	Float	TotalAvgSegDelay/Length (sec/mile)

Table	Field Name	Data Type	Description
	LengthFt	Decimal	Segment Length (ft) = EndM – StartM
tblSpeed VideoGPSPoint GPSpoints			1 second GPS positions. Additional related fields are included in VideoGPSPoint events.
	GPSSpeedId*	integer	1 second GPS position Identifier (Auto Number)
	StudyId	integer	Study Identifier
	RouteId	Integer	Route Identifier for sdeRoute
VideoGPSPoint	PeakPeriodId	integer	Peak Period Identifier 1 = AM 2 = Mid-Day (MD) 3 = PM
VideoGPSPoint	TimePeriodId	integer	Time Period Identifier. Several TimePeriodId's can be within one PeakPeriodId
VideoGPSPoint	DatafileId	Integer	Unique Run Identifier. One record exists for each route the run traverses
VideoGPSPoint	IntSegId	integer	Intersection Segment Identifier based on intersection IntIds: $IntSegID_i = (IntID_{Upstream} * 10000$
VideoGPSPoint	StudyName	Varchar	Name of the study during which this data was collected
VideoGPSPoint	Route	varchar	Directional Route Name
VideoGPSPoint	PeakPeriod	varchar	Peak Period, AM, Mid-Day (MD), PM
VideoGPSPoint	PeriodStartTime	varchar	Time Period Start Time
VideoGPSPoint	PeriodEndTime	varchar	Time Period End Time
	GISFile	varchar	The shapefile that contains the GPS points
	Datafile	varchar	Travel Run Identifier [1234][5][67][8] [1234]=RouteId [5] = PeakPeriodId [67] = EmployeeId [8] = Character [A-Z] to prevent duplicate datafiles

Table	Field Name	Data Type	Description
VideoGPSPoint	ISseg	varchar	[Upstream Intersection] to [Downstream Intersection]
	Speed	decimal	GPS Speed in MPH
	Bearing	decimal	GPS Bearing relative to last position
	PDOP	decimal	Position Dilution of Precision – a measure of the current satellite geometry. The lower the PDOP value, the more accurate the GPS positions.
	GPSDate	datetime	GPS Date
	GPSTime	datetime	GPS Time
	Measure	decimal	Route Measure (ft)
	Offset	decimal	Distance of GPS position from route (ft)
	X	Decimal	GPS easting coordinate
	Y	Decimal	GPS northing coordinate
	Height	Decimal	GPS elevation (±50 ft)
vwVideoDatafile			This tables provides a link to VideoGPSPoint for viewing digital videos
	VideoDatafileId	Integer	Unique identifier (AutoNumber)
	DatafileId	Integer	Unique Run Identifier. One record exists for each route the run traverses
	StudyId	integer	Study Identifier
	Datafile	varchar	Travel Run Identifier [1234][5][67][8] [1234]=RouteId [5] = PeakPeriodId [67] = EmployeeId [8] = Character [A-Z] to prevent duplicate datafiles
	GISFile	varchar	The shapefile that contains the GPS points
	RouteId	Integer	Route Identifier for sdeRoute

Table	Field Name	Data Type	Description
	VideoFileName	varchar	Name of the video file for this run
	VideoGPSTime	datetime	GPS time that corresponds to video elapsed time
	VideoElapsedTime	datetime	Elapsed time into the video when real world time = VideoGPSTime
	StudyName	Varchar	Name of the study during which this data was collected
	Route	varchar	Directional Route Name
	GPSDate	datetime	GPS Date
	PeakPeriodId	integer	Peak Period Identifier 1 = AM 2 = Mid-Day (MD) 3 = PM
	TimePeriodId	integer	Time Period Identifier. Several TimePeriodId's can be within one PeakPeriodId
	StartTime	varchar	Time Period Start Time
	EndTime	varchar	Time Period End Time
	PeakPeriod	varchar	Peak Period, AM, Mid-Day (MD), PM
	StartM	Decimal	Upstream route measure
	EndM	Decimal	Downstream route measure
	Offset	integer	Offset from route for display as GIS event data

Support Tables

The following table lists the SQL views: queries of the data stored in the feature datasets and tables. If exported to MS Access, the views are a snapshot of the data returned by the query and appear as tabular data. The prefix 'vw' indicates a view of the data.

Table	Field Name	Data Type	Description
tblTimePeriod			Time Periods. Data outside these time period is not included in the summary tables or results
	TimePeriodId*	integer	Time Period Identifier. Several TimePeriodId's can be within one PeakPeriodId
	PeakPeriodId	integer	Peak Period Identifier. Several TimePeriodId's can be within one PeakPeriodId 1 = AM 2 = Mid-Day (MD) 3 = PM
	StudyId	integer	Study Identifier
	StartTime	datetime	Time Period Start Time. Includes 5 minutes before dST if necessary.
	EndTime	datetime	Time Period End Time. Includes 5 minutes after dET if necessary.
	DisplayStartTime	datetime	Display Start Time for period
	DisplayEndTime	datetime	Display End Time for period
	Offset	integer	Offset from route for display as GIS event data
	RequiredRuns	integer	The required number of runs on each segment for this time period
	RequiredError	decimal	The minimum error required to reduce the acceptable number of runs
	RequiredConfidence	decimal	The confidence interval required to reduce the acceptable number runs

Table	Field Name	Data Type	Description
tblSignalLOS			Signalized Intersection Level Of Service. The following intersection control applies for this LOS table: Signal Signal - No Stop SPUI Ped Signal
	CtrlDelayLL	decimal	Control Delay Lower Limit (sec/veh)
	CtrlDelayUL	decimal	Control Delay Upper Limit (sec/veh)
	LOS*	char	Level Of Service
tblUnSignalLOS			Stop Controlled Intersection Level Of Service. The following intersection control applies for this LOS table: AWSC Flashing Red Roundabout TWSC Stop
	CtrlDelayLL	decimal	Control Delay Lower Limit (sec/veh)
	CtrlDelayUL	decimal	Control Delay Upper Limit (sec/veh)
	LOS*	char	Level Of Service
tblUrbanLOS			Uncontrolled Intersection Level Of Service. The following intersection control applies for this LOS table: City Limit Cross Section Cross Street Flashing Yellow Jurisdiction
	SpeedLL	float	Average Speed Lower Limit
	SpeedUL	float	Average Speed Upper Limit
	FFSLL	float	Free Flow Speed Lower Limit
	FFSUL	float	Free Flow Speed Upper Limit
	LOS*	char(1)	Level Of Service
tblstat			Two-sided t-distribution statistics used to compute probability of error
	n*	integer	number of runs
	t99	decimal	t-statistic for a 99% confidence interval

Table	Field Name	Data Type	Description
	t95	decima l	t-statistic for a 95% confidence interval
	t90	decima l	t-statistic for a 90% confidence interval
	t85	decima l	t-statistic for a 85% confidence interval
	t80	decima l	t-statistic for a 80% confidence interval
	t75	decima l	t-statistic for a 75% confidence interval

Appendix C – Summary Statistics for Arterial Speed Survey Sites

The following table shows summary statistics for the Phase 2 arterial speed survey sites.

Location						Area type	Facility type	Lanes	Posted speed	Speed			Vol/lane/hr		
ID	County	City	Street	From	To					Min	Max	Avg	Min	Max	Avg
IM 01b	Imperial	Calexico	W Birch St (SR98)	Imperial Ave	Andrade Ave	3	40	2	30	3	44	25	576	1,144	835
LA 01	Los Angeles	Compton	E Rosecrans Ave	N Willow brook Ave	Atlantic Ave	4	40	2	35	4	39	19	800	1,384	1,096
LA 02	Los Angeles	La Puente / West Covina	N Hacienda Blvd (SR39)	N Unruh Ave	E Cameron Ave	3	40	2	40	9	39	23	828	1,332	1,080
LA 03	Los Angeles	Long Beach	E Anaheim St	Junipero Ave	Clark Ave	3	50	2	30	6	37	27	716	1,400	1,068
LA 04	Los Angeles	La Habra Heights	N Harbor Blvd	Fullerton Rd	Orange County Line	5	42	2	45	42	52	46	640	2,216	1,146
LA 05	Los Angeles	La Puente / Hacienda Heights	7th Ave	Valley Blvd	Palm Ave	3	40	1	35	2	40	25	224	1,488	706
LA 06	Los Angeles	Castaic	Henry Mayo Dr (SR126)	Chiquito Canyon Rd	Pico Canyon Rd	5	40	2	60	45	62	58	808	1,400	1,108
OR 01	Orange	E of Tustin	E Santiago Canyon Rd	Jamboree Rd	SR241 on ramp	5	40	1	55	13	56	42	164	1,772	620
OR 02	Orange	Anaheim	W Broadway Ave	N Euclid St	S Harbor Blvd	4	50	2	35	10	37	24	376	856	577
OR 03	Orange	Fullerton	N State College Blvd	Yorba Linda Blvd	Imperial Hwy (SR90)	3	40	2	45	5	46	31	664	1,720	976
OR 04	Orange	Fountain Valley / Costa Mesa	Talbert Ave	Brookhurst	Harbor Blvd	3	40	2	45	7	45	31	320	2,864	1,066
OR 05	Orange	La Habra	Hacienda Rd (SR39)	W Whittier Blvd	Citrus St	5	42	1	35	4	36	26	492	1,120	760
RV 03	Riverside	Riverside	Van Buren Blvd	Victoria Ave	Mockingbird Canyon Rd	5	42	2	55	11	56	42	592	2,172	1,278
RV 04	Riverside	Perris	N Perris Blvd	E 11th St	Nuevo Rd	5	40	1	35	5	30	20	196	784	496
RV 06	Riverside	Riverside	Washington St	Overlook Pkwy	Golden Star Ave	5	50	1	40	25	53	43	360	1,064	629
RV 08	Riverside	Riverside	Market St	SR-60 (EB off)	University Ave	3	40	2	35	4	42	27	424	1,360	865
SB 01b	San Bernardino	San Bernardino	University Pkwy	Hallmark Pkwy	Northpark Blvd	5	51	2	45	1	43	20	400	1,720	961
SB 02b	San Bernardino	Bloomington	Cedar Ave	Bloomington Ave	W Rialto Ave	4	50	2	40	3	42	32	472	1,116	769
SB 04	San Bernardino	Chino Hills	Central Ave	Schaefer Ave	SB on-ramp to NB SR71	4	40	1	45	5	48	34	496	1,572	898
SB 07	San Bernardino	Rialto	E Rialto Ave	Acacia Ave	Rancho Ave	4	50	1	35	4	45	28	268	672	479
VN 01	Ventura	Moorpark	Moorpark Rd	Read Rd	Tierra Rejada Rd	5	50	1	45	23	47	40	344	992	667
VN 02	Ventura	Camarillo	Pleasant Valley Rd	Springville Rd	S Lewis Rd	5	40	1	40	2	51	31	80	1,824	639
VN 05	Ventura	Oxnard	N Rice Ave	Camino Del Sol	Channel Islands Blvd	4	42	2	35	6	56	33	664	1,980	1,207
VN 06	Ventura	Simi Valley	Madera Rd	Wood Ranch Pkwy	E Los Angeles Ave / Tierra Rejada Rd	5	40	2	45	8	52	36	724	2,096	1,169